THEORY AND USE OF ELECTRONIC TEST EQUIPMENT

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Figure 1. Test instruments, properly used, help the technician place equipment in operation, and aid in maintenance and repair.

SECTION I

THEORY OF METERS

1. Importance of Test Equipment

A technician may be required to put new apparatus in operation, to maintain equipment so that it continues to operate, and to repair equipment that has broken down. Many test instruments are available to help him to do these jobs efficiently. To place in operation and maintain new apparatus he is aided by test equipment such as signal generators, voltmeters, ammeters, frequency meters, and output meters. When there is a breakdown, multimeters, vtvm's (vacuum-tube voltmeters), signal tracers, tube checkers, and other devices help locate the trouble quickly and efficiently (fig. 1). Since the technician must understand how these devices work and how to use them correctly, this manual describes the theory and use of nearly every important radio test instrument. Meters are the most commonly used of all test equipment and, therefore, a brief outline of the different kinds is given in this chapter.

2. Basic Meter Principles

a. PURPOSE. Meters are used to measure electrical quantities. Some meters measure voltage, current, resistance, or all three. Others measure power, capacitance, or other electrical quantities. Whatever the meter is designed to measure, its operation depends (except in an electrostatic meter) on the passage of an electric current through it.

b. USE OF CURRENT METERS. Since meters cannot indicate measurements without a flow of current through them, it might seem that they can be used only to measure current. This is not true. A meter circuit can be modified and the meter calibrated to read almost any of the basic electrical units. For example, a meter can be used to measure voltage even though it registers only because of the current through it. It is possible to do this because the current through the meter varies in exact proportion to the voltage across the circuit (Ohm's law). The face of the meter then can be calibrated in volts rather than in amperes. Also, the amount of resistance in a circuit directly affects the current in the circuit, and, if desired, the meter can be calibrated in resistance units instead of current or voltage units.

c. PROPERTIES OF CURRENT FLOW. Two fundamental properties of current flow—*electromagnetism* and *heat*—are used to make meters function.

(1) When current flows through a coil, a magnetic field is created that is directly proportional to the amount of current. The strength of this field can be used in several different ways to indicate the amount of current passing through the coil. Three classes of meters use electromagnetism: *moving-iron* meters, *moving-coil* meters, and *dynamometers.*

(2) When current flows through a wire, the amount of heat produced is directly proportional to the current flow. Consequently, the amount of heat can be used to indicate the amount of current. Meters using this principle are called *thermal* meters. The two main classes are *hot-wire ammeters* and *thermocouple* meters.

3. Electromagnetic Meters

a. MOVING-IRON METERS.

(1) *Basic principle.* If a soft-iron bar is placed near an electromagnet, the bar becomes magnetized (fig. 2). The molecules of the bar line up, and the lines of force through the bar are in

the same direction as the lines of force coming from the electromagnet. Since the lines of force act like stretched rubber bands, they try to shorten themselves, and the bar is attracted to the electromagnet. If the coil is fixed and the bar is free to move, the bar is pulled into the coil. When the current through the coil reverses, the molecules in the iron bar reverse. The reversed lines of force in the bar line up with the reversed lines of force coming from the coil, and the bar again is attracted to the coil. The soft-iron bar therefore is attracted to the electromagnet whether dc (direct current) or ac (alternating current) flows through the coil. Soft iron is used because it demagnetizes when the current through the electromagnet stops. There are two types of moving-iron meters—the *plunger-type* and the *repulsion-type moving vane.*

(2) *Plunger type.* The movable soft-iron bar with a pointer attached is placed partially inside the fixed coil (fig. 3), and the pointer-bar assembly is fastened to a pivot, A. When current flows through the coil, a magnetic field is set up. The soft-iron bar becomes magnetized and is pulled farther into the coil, moving the pointer. The distance the pointer is moved is proportional to the strength of the magnetic field, which depends on the amount of current through the coil. The plunger type was an early meter used to measure ac and is now obsolete.

(3) *Repulsion-type moving vane.* This meter, like the plunger type, operates on the principle that an electromagnet magnetizes soft iron. Two iron bars are used instead of one, and both are placed completely inside the coil. When current flows, the bars are magnetized with the same polarity (fig. 4) and,

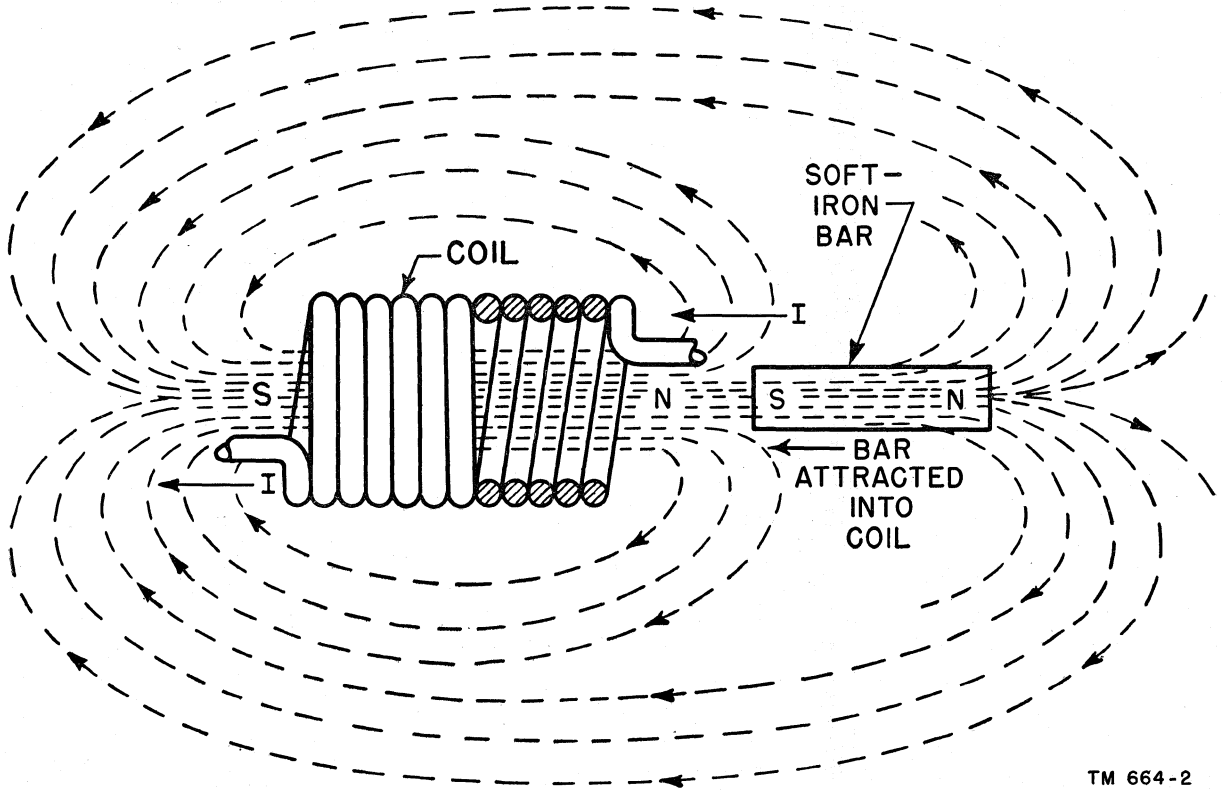


Figure 2. Effect of lines of force from current-carrying coil on soft iron bar.

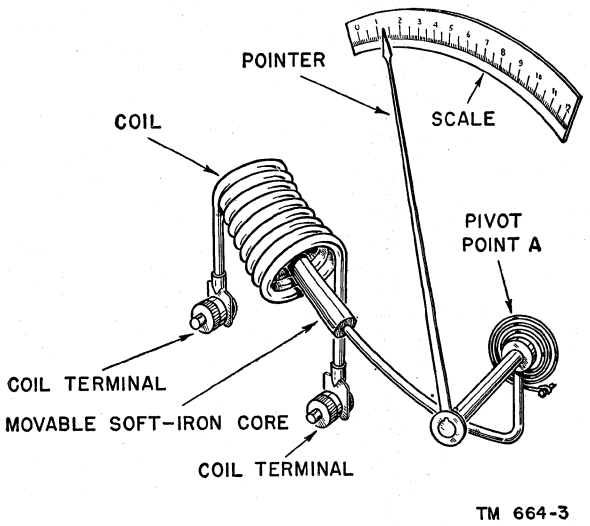


Figure 3. Moving-iron meter, plunger type.

because like poles repel, the bars move apart. If the current reverses, the polarity of the bars reverses at the same time, and they still repel each other. When one bar is fixed and the other free to move, the force of repulsion can be made to indicate the amount of current flow by attaching a pointer to the movable bar. Two groups of meters use the repulsion principle. They are the *radial-vane* and the *concentric-vane* meters.

(*a*) In the radial-vane meter, two rectangular vanes are placed inside the coil (fig. 5). One vane is fixed, and the other is free to rotate on pivots and has a pointer attached. When current flows through the coil, the iron vanes become magnetized and repel each other. The movable vane swings away, carrying with it the pointer that indicates on the scale the current passing through the coil.

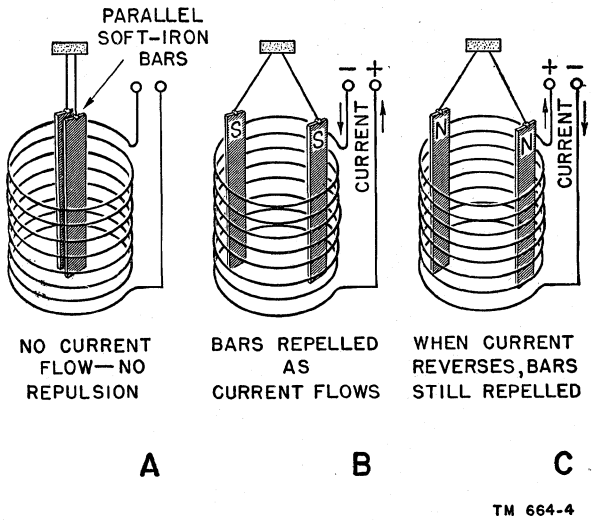


Figure 4. Effect of iron bars in electromagnet.

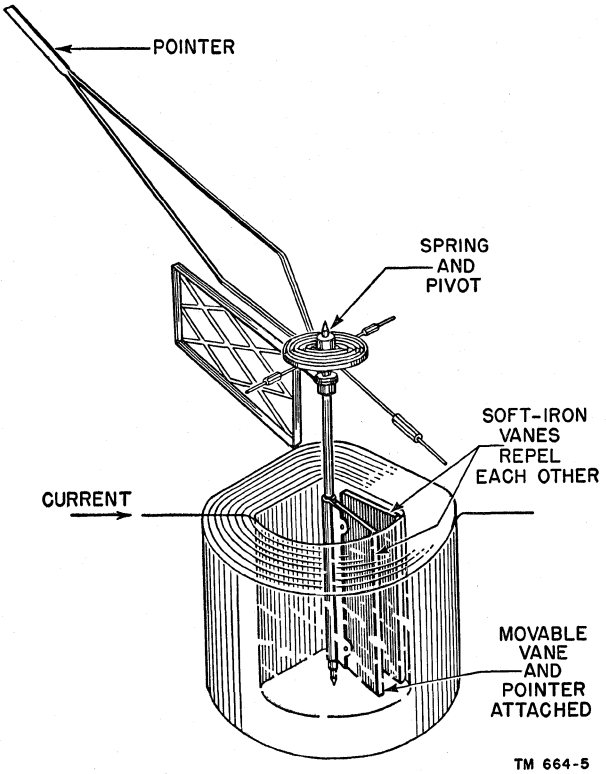


Figure 5. Radial-vane meter.

(*b*) The concentric-vane meter works on the same general principle and is described as concentric because the semicircular vanes are placed one inside the other (fig. 6). One vane is fixed and the other is free to move on pivots, with a pointer attached. Although repulsion-type meters can be made to measure ac or dc, they are used generally to measure low-frequency ac.

b. MOVING-COIL METER.

(1) Most of the meters used by technicians embody the moving-coil principle of

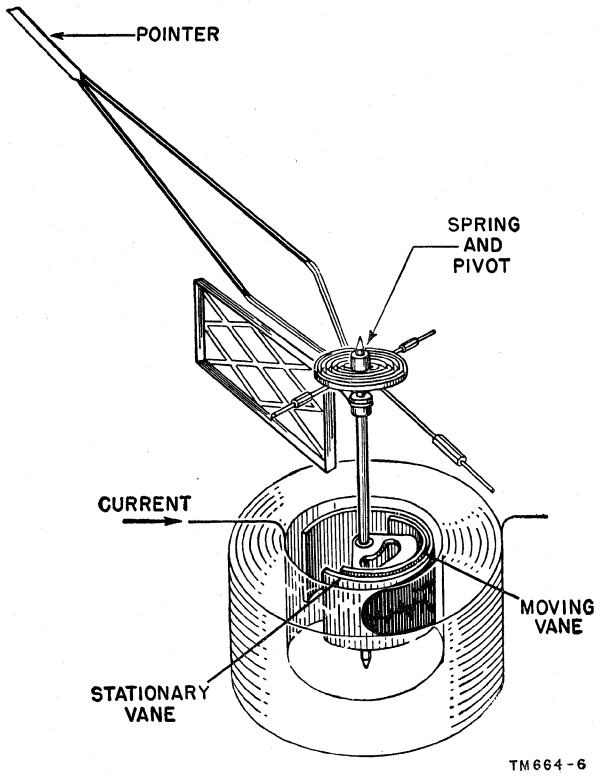


Figure 6. Concentric-vane meter.

operation. The moving-coil meter uses a coil of fine wire wound on a light aluminum frame with a permanent magnet surrounding the coil (fig. 7). The coil is placed on pivots on the ends of the frame which allows the coil to move freely, and springs are attached to it to control the amount of needle swing. When current flows through the coil, it becomes magnetized, and the polarity of the coil is such that it is repelled by the permanent magnet. A pointer attached to the coil frame swings with the coil, and indicates on the scale the amount of current flowing through the coil. This meter movement can be made so sensitive that a few microamperes of current will swing the pointer across the entire scale. If the pointer and zero indication are placed at the center of the scale, the movement can be used for making accurate resistance, capacitance, and inductance measurements in bridges and can be modified for use as a *d-c ammeter* or a *voltmeter*. It can be made to measure ac by applying the ac to the meter through a suitable rectifier, and measuring the rectified current.

(2) Because the moving-coil meter is rugged, accurate, and capable of measuring d-c voltage and current, a-c voltage, and also resistance, it is used invariably in the *multimeter*, a combination volt-ohm-ammeter. This meter movement is used also in the vtvm and is by far the most important type of meter in radio and electrical work.

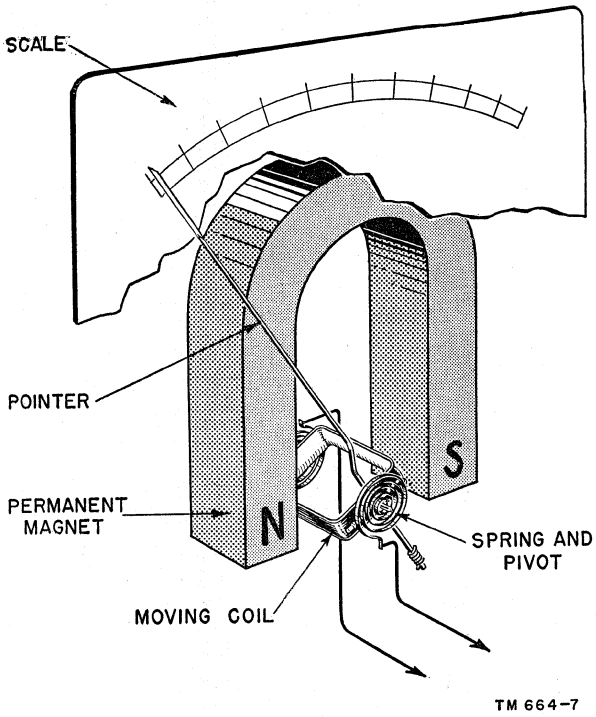


Figure 7. Moving-coil meter.

c. DYNAMOMETER. The *dynamometer* is based on the principle of magnetic repulsion between two or more electromagnetic fields. When two coils are used, one is fixed and the other has a pointer attached and is pivoted for free movement. Current passes through both coils, and magnetic fields are created. The movable coil, with the attached needle, is repelled by the like poles of the fixed coil and swings away, carrying the pointer with it. The dynamometer can measure a-c and d-c voltage, current, and power,

although it is used commonly to measure power in watts (fig. 8). When used as a wattmeter, two fixed coils wound with many turns of small wire and having a high resistance are connected in series across the voltage source of the circuit. A movable, low-resistance coil is placed in series with one connection, and the entire circuit current flows through it. The strength of the field around the low-resistance coil depends on the current in the circuit. The low-resistance movable-coil and indicating-needle (pointer) assembly swings a distance proportional to the *combined* strength of the two magnetic fields. The swing therefore is proportional to both the current and the voltage in the circuit. Since power also is proportional to the current and voltage, the meter can be calibrated in watts, the unit of power.

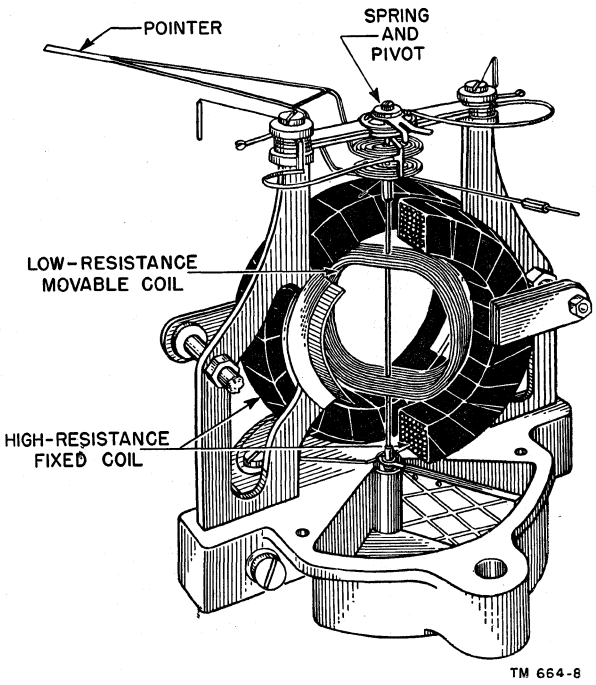


Figure 8. Dynamometer, Low-resistance movable coil with two high-resistance fixed coils.

4. Thermal Meters

a. HOT-WIRE AMMETER. The heat generated by current flowing in a wire will cause the wire to expand. In the hot-wire ammeter the expanding wire moves a pointer which indicates the current in the circuit on the scale of the meter. The meter is connected in series with the load by means of terminals A and B (fig. 9). Within the meter, wire 1 is connected between the two terminals. Wire 2 is attached to the first wire near the center and the amount of tension applied to wire 1 is controlled by the tension spring. Wire 2 passes along the round base of a pivoted indicating needle and is used as a drive wire to move the needle. When current passes through wire 1, the heat is proportional to the strength of the current. The higher the current, the greater the heat generated and the more wire 1 expands. As wire 1 expands, it is pulled down by the tension of the spring and wire 2 rides along the base of the pivoted needle, driving the needle across the scale. The needle is adjusted to read 0 with 0 current by means of the adjustment screw regulating the sag in wire 1.

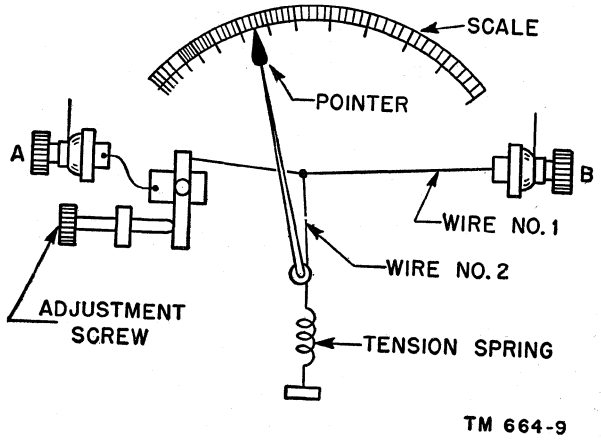


Figure 9. Hot-wire ammeter.

b. THERMOCOUPLE METER.

(1) If 1 ampere of current flows through a wire, a certain amount of heat is produced. The quantity of heat is exactly the same for 1 ampere of current whether the current is low-frequency ac, high-frequency ac, or dc. The thermal effect therefore can be used to measure any kind of current. Thermocouple meters generally are used to measure high-frequency ac. The thermocouple meter is used in transmitters to measure r-f (radio-frequency) antenna current and r-f power.

(2) The thermocouple meter is placed in series with the circuit under test, so

that the circuit current passes through wire A of the meter (fig. 10). Wire A is attached to the junction of two different metals, and this bimetallic strip forms the *thermocouple.* The thermocouple has the property of generating a d-c voltage when the junction of the dissimilar metals is heated. The current heats the wire, the hot wire heats the thermocouple, and a small d-c voltage is generated which appears across terminals C and D, and is proportional to the amount of heat. Within limits of the thermocouple, the more current in the circuit the more heat at the junction, and the greater the d-c voltage generated. The voltage across C and D then is applied to a moving-coil d-c meter. It should be emphasized that either ac or dc can be sent through wire A to heat the thermocouple. *Whatever the kind of current passing through the wire and being measured, only d-c voltage appears at the free ends of the thermocouple.* The thermocouple meter can be said to combine both the thermal and the electromagnetic principles of operation.

5. General Meter Considerations

a. The meters described above can be used to measure either ac or dc by modifying the meter circuits and calibrating the meter scale in terms of the desired unit. The repulsion or moving-vane meter commonly is used for a-c measurements. In electrical and radio work, thermocouple meters are used exclusively for r-f measurements; moving-coil meters are used for almost all other measurements. The detailed discussion of these meters in the following chapters includes the advantages and limitations of each type. Information will be given on the meter characteristics listed below.

(1) *Accuracy.* Some meters are basically more accurate than others.

(2) *Interference with circuit operation.* Some meters, when connected in a circuit under test, alter the circuit conditions. The changes caused by the meter result in inaccurate measurements. Other meters have practically no effect on the circuit under test, and give more accurate readings.

(3) *Scale used.* Scales on some meters are linear, (with even spaces between numbers); other meters have nonlinear scales.

b. With this information, the technician can determine the best type of meter for a given purpose. In emergencies, he also will know how to modify any type of meter to suit his needs.

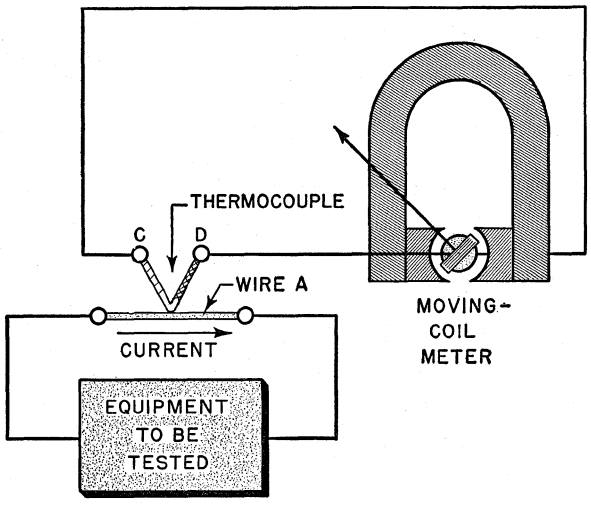


Figure 10. Thermocouple-type meter.

6. Summary

a. Meters are used to measure electrical quantities.

b. All meters, except electrostatic meters, regardless of the unit being measured, are operated by current flowing through the meter movement.

c. The fundamental properties of current flow used to make meters function are electromagnetism and heat.

d. Three classes of meters use the electromagnetic principle: moving-iron meters, moving-coil meters, and dynamometers.

e. Two classes of meters use the thermal principle: hot-wire ammeters and thermocouple meters.

7. Review Questions

a. What is the purpose of test equipment?

b. What are meters used for?

c. What is meant by the calibration of a meter?

d. What do most meters actually measure?

e. How can meters be used to measure various electrical quantities?

f. What are two basic properties of current flow?

g. What are the two main meter types?

h. Name the principal classes of meters under each basic type.

i. What is the basic principle used in moving-iron meters?

j. How is this principle applied in plunger-type meters?

k. Explain how this principle operates in repulsion-type moving-vane meters.

l. Explain the operation of moving-coil meters.

m. What kind of measurements can be made with moving-coil meters?

n. How do dynamometers operate?

o. Explain the operation of a hot-wire ammeter.

p. Outline the operation of a simple thermocouple meter.

q. Where are thermocouple meters usually found? Why?

SECTION II

D-C AMMETERS AND VOLTMETERS

8. Construction and Operation of Moving-Coil Meter

a. D'ARSONVAL MOVEMENT. The meter most commonly used in radio and electrical work is the moving-coil meter, preferred because of its accuracy, ruggedness, and linear scale. In 1882, Arsene d'Arsonval, using the moving-coil principle, developed a galvanometer, which is simply an unmodified meter movement measuring very small currents. In 1888, Dr. Edward Weston modified the design considerably to make the meter easily portable. The basic movement still is referred to as the d'Arsonval movement.

b. CONSTRUCTION.

(1) The moving-coil meter uses a horseshoe permanent magnet with soft-iron, semicircular pole pieces added to its ends (A, fig. 11). The magnet has a strong *nonuniform* magnetic field between the pole pieces that is not suitable for meter operation. A circular soft-iron core inserted between the pole pieces, however, results in a strong, *uniform* magnetic field in the spaces, and also helps the permanent magnet to retain its magnetism by acting as a keeper.

(2) The moving coil consists of several turns of fine wire wound on a rectangular aluminum frame (B, fig. 11). Because the coil must be light and able to swing freely, only a limited number of turns can be placed on the frame. The fine wire allows the coil to carry only a small amount of current and this amount varies with different models. Very little current is necessary to cause a full-scale deflection of the needle.

(3) The coil assembly is mounted in the air space between the pole pieces of the permanent magnet and the soft-iron core. Hardened-steel pivots are attached to the frame at the points where the springs are located, and the pivots fit into jeweled bearings, allowing the coil to turn with a minimum of friction (C, fig. 11). The indicating needle is attached to the coil assembly, swinging with it, and tiny counterweights are used to balance the assembly on its pivots. The two ends of the coil are connected to two springs, one on each side of the aluminum frame. The other ends of these springs go to the external circuit, from which current is fed to the coil. A screw on the front of the movement zero-adjusts the pointer to zero-scale reading for zero current (D, fig. 11).

c. BASIC OPERATING SYSTEMS. The moving-coil meter includes three basic systems in its overall operation:

(1) *Motor system.* The pointer must indicate the amount of current passing through the meter. This is accomplished by the motor system. When dc passes through the coil, the coil becomes magnetized, and is repelled by the permanent magnet. The pointer, swinging with the coil, registers a reading on the scale according to the amount of current flowing through the coil. The greater the current, the stronger the magnetic field around the coil, the greater the repulsion, and the farther the coil and pointer move. When current passes through the coil in the opposite direction, an opposite magnetic field is set up and the coil

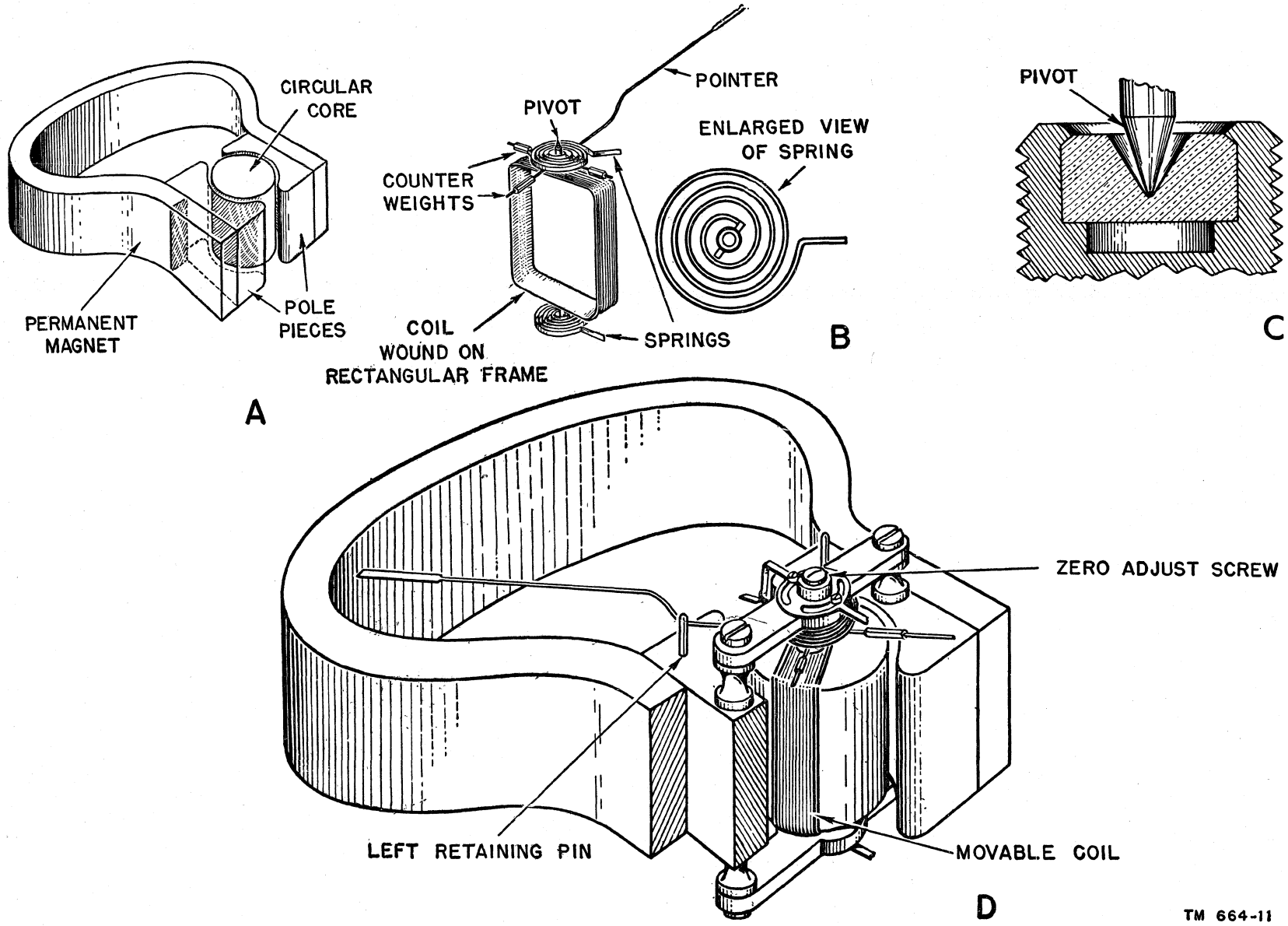


Figure 11. Component units of moving-coil meter movement.

is repelled in the opposite direction. The needle moves *backward,* hitting against the left retaining pin instead of moving to the right across the scale. Current, therefore, must be applied to the meter with the correct polarity so that the coil will turn the needle in the right direction. The needle cannot swing off-scale on the extreme right because of the right retaining pin.

(2) *Control system.* The pointer must indicate accurately the amount of current passing through the coil and return to 0 when the meter is removed from the circuit. These two operations are governed by the control system. The springs connected to the coil furnish the control action in the meter because:

(*a*) They regulate the amount of rotating action by the coil. For this reason they must be made with precision if the meter is to register accurately.

(*b*) They bring the coil and needle back to the 0 position when current through the coil stops flowing.

(*c*) They conduct current to and from the coil.

(*d*) They are oppositely wound to compensate for temperature changes. When current flows and the coil turns, one spring tightens as the other loosens. When the meter is removed from the external circuit, current through the coil stops flowing. Both springs return to their normal position, bringing the coil back to the 0 point. It is not necessary to wind springs in opposite directions to bring the coil back to 0. The advantage of oppositely wound springs lies in their compensating action when the temperature changes. A change of temperature causes the springs either to contract or expand. If both springs contract (or both expand), one spring tries to move the coil in one direction; the other, oppositely wound, tries to move it in the other direction. Because they are matched springs, their actions cancel and the needle remains at the 0 position. This makes it unnecessary to zero-set the meter every time there is a change of temperature. The springs usually are made of nonmagnetic phosphor bronze, and have a low resistance to current flow. Since the springs are good conductors, they are used to carry the current from the coil assembly to the external connections of the meter. Moving-coil meters have a zero-adjust screw which physically moves one spring (D, fig. 11) and varies the position of the coil and needle to some extent. If the needle is not on 0 when there is no current flowing through the meter, it should be zero-set by adjusting this screw before any readings are taken.

(3) *Damping system.* The needle must come to rest quickly at the correct point without vibrating. The method used to accomplish this is called damping. The damping system varies with different types of meters.

(*a*) *Damping action.* The object of damping is to get quick, correct indications from the pointer without having it swing back and forth before coming to rest. Damping is the equivalent of *braking* action on the needle swing. In the moving-coil meter, damping usually is accomplished by the aluminum frame on which the coil is wound. When the coil moves to register current flow, the aluminum frame itself acts like a one-turn coil. This frame cuts across the magnetic lines of force from the permanent magnet and a voltage is induced in it. Large eddy currents flow through the frame and set up a magnetic field around it which opposes the magnetic field of the permanent magnet. The braking action which results slows the

movement of the coil. As soon as the coil comes to rest, no further voltage is induced in the aluminum frame, and eddy currents no longer flow. When the coil returns to the zero position, the same process takes place in the aluminum frame. Briefly, eddy currents induced in the frame create a magnetic field that opposes the field of the permanent magnet and tends to oppose or brake the action of the springs in returning the coil to zero.

(*b*) *Ammeter damping.* A low-value resistance called a shunt is placed in parallel with the meter movement when it is to be used as an ammeter. Since the shunt parallels the meter movement, the current flows through both the meter coil and the shunt. When the coil starts to turn, the counter emf generated in it bucks the original current, and acts to cut it down until the coil stops moving. The counter emf gradually decreases and the current through the coil gradually increases toward its normal value until the coil comes to rest. The current through the shunt momentarily varies to compensate for the changes of current through the coil. When the meter is removed from the external circuit, the coil starts to return to zero, cutting the lines of force, and a voltage is generated across it. Since there is a shunt across the coil which closes the circuit through it, current flows momentarily from one end of the coil through the shunt to the other end of the coil and back again. This results in a magnetic field that bucks the field of the permanent magnet and acts as a brake on the return motion.

9. Meter Characteristics

a. INTERNAL RESISTANCE. Every meter coil has a definite amount of d-c internal resistance which depends on the number of turns on the coil and on the size of the wire used. When more windings are placed on the coil, a smaller amount of current is necessary to create a magnetic field strong enough to deflect the coil full scale.

b. SENSITIVITY OF METER MOVEMENT. Meter sensitivity can be defined in two ways—as the amount of current necessary for full-scale deflection and as the ohms per volt. The amount of current necessary for full-scale deflection depends on the number of turns on the coil. When more turns are added, a stronger magnetic field is created and a smaller amount of current is necessary for full-scale deflection. Sensitivities vary from 5 μa (microamperes) to approximately 50 ma (milliamperes) and the smaller the amount of current necessary for full-scale deflection of the meter, the greater the sensitivity. The sensitivity in ohms per volt is determined by the amount of resistance that must be placed in series with the meter to cause full-scale deflection when 1 volt is applied. The more resistance placed in series with the meter, the greater the sensitivity in ohms per volt. Internal resistance may vary from a fraction of an ohm to several hundred ohms, but is usually small enough to be disregarded. *Sensitivity and internal resistance are characteristics of the meter movement itself. They cannot be altered unless the construction of the movement is changed.*

c. ACCURACY.

(1) Moving-coil meters made for laboratory use have a very high accuracy (.1 of 1 percent), and some semiprecision meters are accurate to .5 of 1 percent. The accuracy of meters for general use, however, is within 2 percent. The *accuracy percentage* refers only to full-scale readings on any range. For example, a meter is rated as being accurate within 2 percent on the 500-volt range. At full-scale deflection, the reading will be accurate within 2 percent, or within ± 10 volts. Actually, if a lower voltage is read on that scale, and is 10 volts off, the inaccuracy becomes greater than 2 percent. The smaller the reading, the greater will be the percentage of inaccuracy. Most meters, however, give a greater degree of accuracy along the scale than is

guaranteed. It should be remembered that the accuracy of voltage and current readings on moving-coil meters tends to be greater when the readings are taken closer to full-scale deflection.

(2) When a meter is inserted in a circuit, an interesting point sometimes arises in connection with the meter accuracy. *Inaccurate readings result because circuit operation has been changed and not because the meter is registering incorrectly.*

d. SCALE. Most moving-coil meters used for d-c measurements have a linear scale with equal spaces between numbers, similar to the one shown in figure 12. The amount of deflection is directly proportional to the amount of current through the coil, and when the rated current flows through the meter the pointer deflection is full scale. When half the rated current flows through the coil, the pointer deflection is half-scale, and so on. For example, point A on the scale corresponds to a reading of 1.2, point B reads 6.5, and point C, 8.8. Nonlinear scales are discussed later in this text.

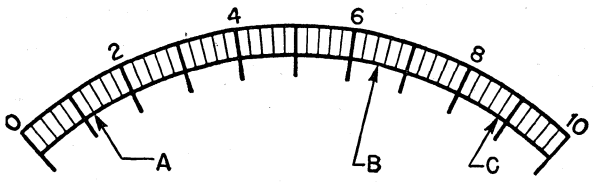


Figure 12. Linear scale used in moving-coil meters for d-c measurements.

10. Extending Range of Meter Movements

a. In radio or electrical work the meter must be capable of measuring d-c voltages ranging from a fraction of a volt to 500 volts or higher. Direct-current measurements ranging from a fraction of a milliampere to 1 ampere or more and several ranges of resistance measurement are necessary. Unless individual meters for each range are to be used, some provision must be made to modify the meter circuits so that only one meter is necessary.

b. Attempting to measure currents higher than the sensitivity rating of the meter movement being used causes too much current to flow through the meter, with resultant damage. Since there is too much current through the coil, the needle turns past full-scale deflection, hitting the right retarding pin, and this current overload can result in a bent needle, a burnt coil, or both. For example, assume that a 1-ma meter movement with an internal resistance of 27 ohms is placed across 1 volt. Only 1 ma is necessary to cause the needle to make a full-scale deflection. According to Ohm's law, the current flow through this movement when placed across 1 volt would be:

$$I = \frac{E}{R} = \frac{1}{27} = .037 \text{ ampere or } 37 \text{ ma.}$$

A current of 37 ma is flowing through a meter movement which is designed to deflect full scale when 1 ma passes through it.

c. The external circuit of the meter must be modified before it can be used to measure the range of voltages and currents found in radio and electrical circuits. To use the movement as a voltmeter, a high resistance (multiplier resistor) is added in series with the meter movement. This reduces the current to an amount the meter can handle safely, even though it is placed across a high voltage. To use the movement as an ammeter, a low resistance is placed in parallel with the movement to provide another path for the current. Part of the current flow in the circuit is bypassed by the parallel resistor, and a small portion of the circuit current flows through the meter movement. This small current can be handled without injury to the meter.

d. The rules, then, for modifying the external meter circuit are:

(1) For use as a voltmeter, place a high resistance in series with the meter movement.

(2) For use as an ammeter, place a low resistance in shunt (parallel) with the meter.

11. Basic Voltmeter

a. FINDING MULTIPLIER RESISTORS BY OHM'S LAW.

(1) To find the series resistance necessary to measure any given voltage, the full-

scale deflection, internal resistance of the meter, and voltage range to be measured must be known. The necessary series resistor then can be determined by Ohm's law. For example, it is desired to use a 1-ma movement with 27 ohms internal resistance to measure 10 volts at full-scale deflection (fig. 13). The maximum current permissible through the movement is 1 ma. Since the voltage (10 volts) and the current (1 ma) are known, the total meter-circuit resistance must be:

$$R = \frac{E}{I} = \frac{10}{.001} = 10{,}000 \text{ ohms.}$$

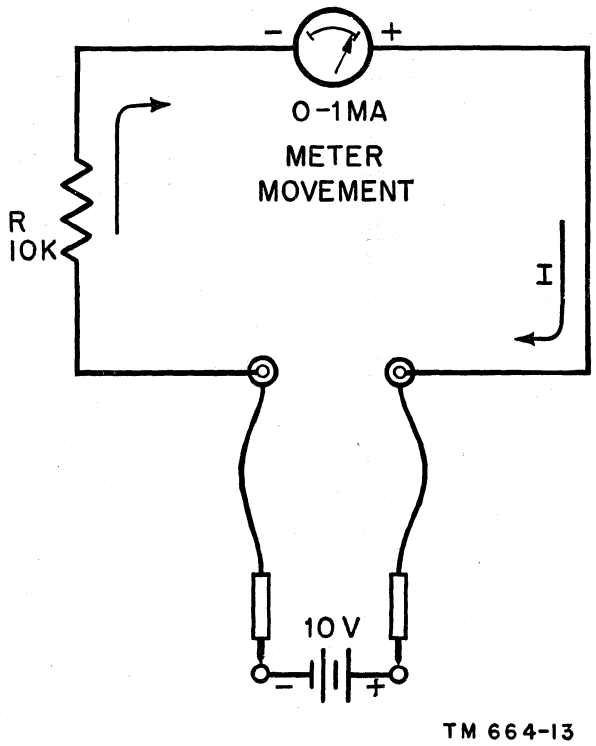


Figure 13. Series R limits current through meter movement when used as voltmeter.

(2) When the series resistance is very large compared with the internal resistance, the internal resistance need not be deducted from the value of series resistance required. In a circuit where the applied voltage is 10 volts, and a resistance of 10,000 ohms is placed in series with the meter movement, 1 ma will flow through the circuit, and the needle will swing to maximum. The voltmeter, therefore, can measure 10 volts without damage if it has a resistance of 10,000 ohms placed in series with it. The series resistance is known as a multiplier, since it extends the voltage range of the meter.

(3) The scale of the meter then can be calibrated in volts, with 10 volts representing full-scale deflection. If the meter is put across 5 volts, only .5 ma flows through the meter movement. Since $I = E/R = 5/10{,}000 = .0005$ ampere = .5 ma this is only half the maximum current the coil can handle. Therefore, only half as strong a magnetic field exists, and the meter will read half-scale. Midscale represents 5 volts, quarter-scale deflection represents 2.5 volts, and other readings will be proportional.

(4) By using the method described above, it is possible to extend the range of the meter movement to any desired amount. To extend the range of the meter to measure 500 volts with full-scale deflection, Ohm's law is used to find the resistance necessary to limit the current to the amount the movement can handle. Using the same 1-ma movement as previously, the series resistance needed is:

$$R = \frac{E}{I} = \frac{500}{.001} = 500{,}000 \text{ ohms.}$$

By putting 500,000 ohms in series with the movement, the meter now can be placed across 500 volts. Only 1 ma of current will flow through the meter movement, or just enough to make the needle deflect full scale.

b. FINDING MULTIPLIER RESISTANCE BY OHMS PER VOLT.

(1) Another method for calculating a multiplying resistor is based on *ohms per volt*—the alternate expression for meter sensitivity. Since current equals E/R and ohms per volt equals R/E,

the current sensitivity in ohms per volt is:

$$\text{Ohms per volt sensitivity} = \frac{1}{\text{current sensitivity}}$$

For example, a given meter movement has a current sensitivity of 1 ma. This means that 1 ma of current makes the needle deflect full scale. It is desired to have the meter measure 10 volts full scale. Current sensitivity can be translated into *ohms per volt* by calculating the amount of resistance that must be placed in series with the meter to measure 1 volt.

(2) To measure 1 volt, the resistance required in series with this 1-ma meter movement is:

$$R = \frac{E}{I} = \frac{1}{.001} = 1{,}000 \text{ ohms.}$$

To measure 1 volt with full-scale deflection, 1,000 ohms must be placed in series with the movement. To measure 10 volts at full scale, it is necessary to put 10 times 1,000 or 10,000 ohms in series with the movement. Therefore, a 1-ma movement can be called a 1,000-ohms-per-volt movement. It is usual to find meter-movement sensitivity expressed in ohms per volt, since it is easier to determine what multiplier resistance is necessary for any desired range.

(3) If it is desired to extend the range of a 5,000-ohms-per-volt movement with an internal resistance of 75 ohms to 300 volts, the ohms-per-volt sensitivity need only be multiplied by 300 volts:

$$300 \times 5{,}000 = 1{,}500{,}000$$
or 1.5 megohm.

The internal resistance can be ignored for all practical purposes.

(4) The ohms-per-volt rating is another way of expressing meter sensitivity. The less current required for full-scale deflection, the more resistance must be placed in series with the movement to measure each volt and, therefore, the greater the sensitivity. When the ohms-per-volt rating is given, it is necessary only to multiply this figure by the desired range in volts to get the required value of multiplier resistance.

12. Multirange Voltmeters

a. SEPARATE MULTIPLIERS. It is possible to have a voltmeter (fig. 14) with several ranges, by using either a switching arrangement, as in A and C, or separate pin jacks for each range, as in B and D. For example, it is desired to have a switching arrangement with four ranges and separate multipliers, using a 2-ma, 18-ohm meter movement. The ranges required are 5 volts, 50 volts, 250 volts, and 500 volts (A, fig. 14). The first step is to convert the current sensitivity into ohms per volt: Ohms-per-volt sensitivity $= \frac{1}{\text{current sensitivity}} = 1/.002 =$ 500 ohms per volt. The multiplier resistor R_1 for the 5-volt range is, therefore, 5 times 500, or 2,500 ohms. R_2 for the 50-volt range is 50 times 500, or 25,000 ohms. R_3 for the 250-volt range is 250 times 500, or 125,000 ohms. R_4 for the 500-volt range is 500 times 500, or 250,000 ohms. Resistors R_1, R_2, R_3, and R_4 are connected to the switch as shown in A and any of the four ranges can be selected by setting the switch to the voltage range desired. In B, the resistors are connected to pin jacks instead of a switch. The common or negative lead is placed in the negative pin jack and the other lead is placed in the positive pin jack of the voltage range desired.

b. SERIES MULTIPLIERS.

(1) D of figure 14 shows a series-multiplier arrangement using pin jacks. One test lead is inserted in the common pin jack (negative terminal) on all ranges. The other test lead is inserted in the pin jack for the desired voltage range. Since this is a series-multiplier arrangement, it is necessary to compute the value of the multiplier resistance for the lowest range first, or R_1. Then the total multiplier resistance for the next higher range is found. R_1 then is subtracted from this figure, and the remainder is the value of R_2. For example, it is desired to have a voltmeter with five ranges using a .5-ma or 500-microampere, 55-

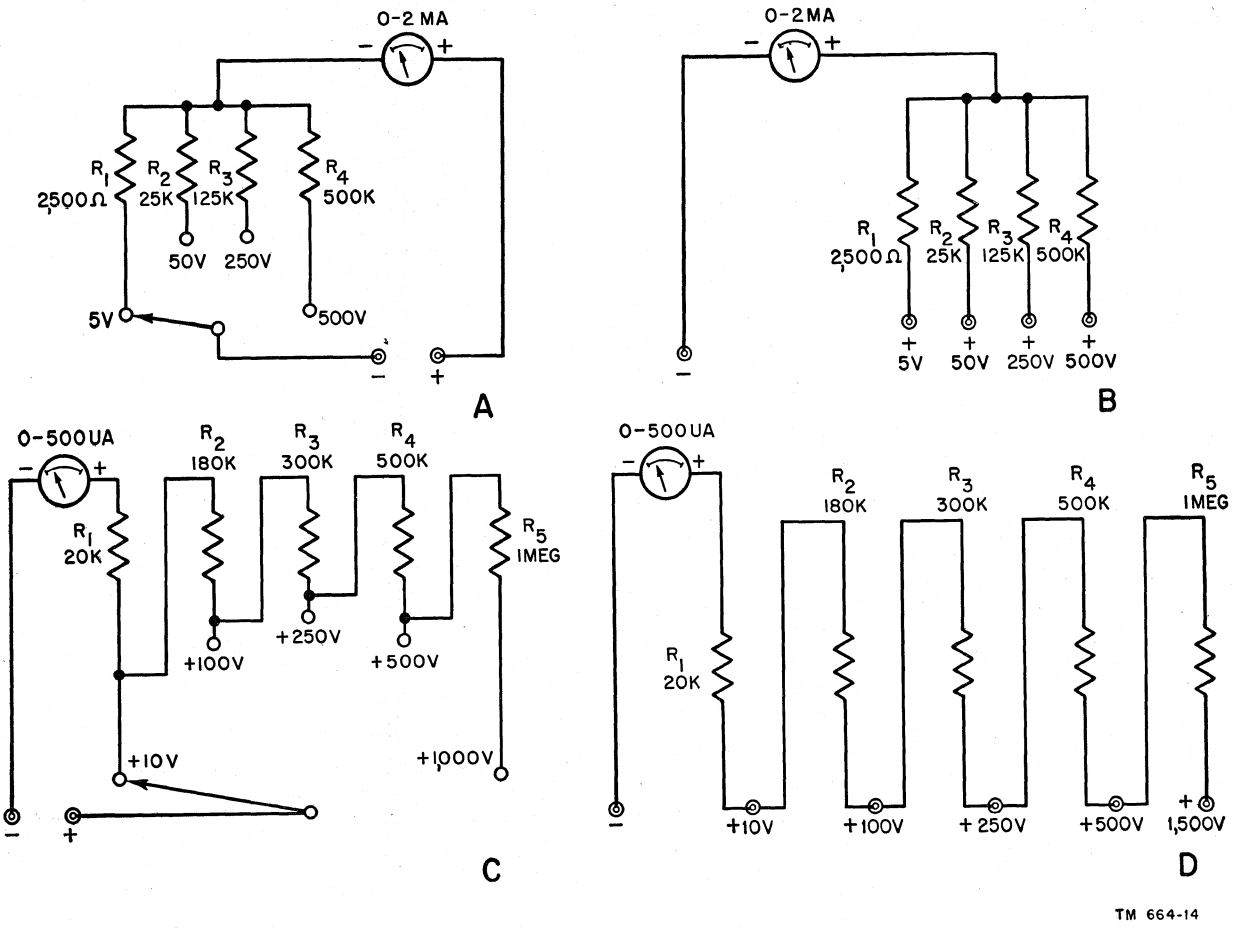


Figure 14. Different types of multirange voltmeters.

ohm movement. Ranges are to be 10, 100, 250, 500, and 1,500 volts. Since the current sensitivity is .5 ma, the ohms-per-volt sensitivity is 1/.0005, or 2,000 ohms per volt. R_1, the multiplier for the 10-volt range, is 2,000 times 10, or 20,000 ohms.

(2) For the 100-volt range, a resistor of 100 times 2,000, or 200,000 ohms, is necessary. However, in this type of meter, the second multiplier, R_2, is in series with R_1. Since the 20,000-ohm resistor, R_1, is in series with meter, R_2 will be equal to 200,000 minus 20,000, or 180,000 ohms. When the test lead is in the 100-volt pin jack, a total of 200,000 ohms is in series with the meter movement, which is the multiplier necessary for this range. The 200,000-ohm multiplier is made up of R_1 (20,000 ohms) and R_2 (180,000 ohms).

(3) For the 250-volt range, the multiplier resistance necessary is 250 times 2,000, or 500,000 ohms. R_1 and R_2 already provide 200,000 ohms; therefore R_3 need provide only the difference between 500,000 and 200,000, or 300,000 ohms.

(4) For the 500-volt range, the multiplier resistance is 500 times 2,000, or 1,000,000 ohms. Since R_1, R_2, and R_3 already provide 500,000 ohms in series, R_4 must provide the difference between 1,000,000 and 500,000, or 500,000 ohms.

(5) In the same way, for the 1,500-volt range, there must be 1,500 times 2,000 or 3,000,000 ohms. Since 1,000,000 ohms are already in series, R_5 need

provide only the additional resistance. This is 3,000,000 minus 1,000,000, or 2,000,000 ohms.

c. TYPES OF MULTIPLIERS. Resistors used as multipliers can be either the carbon or the wire-wound type. The more expensive meters use precision wire-wound resistors with a tolerance of .1 percent. The carbon resistor also can be used as a multiplier if its value is within tolerance limits. This resistor is found in the cheaper instruments where a precise reading is not necessary and an approximate reading can be tolerated. It may serve also as an emergency replacement to keep needed test equipment in service.

13. Basic Ammeter

a. FUNCTION OF SHUNTS. To measure current, the circuit under test is broken and an ammeter is inserted in the break. When the meter is in series with the other circuit components, and the full circuit current to be measured is more than the meter movement can handle, a shunt or small resistor can be inserted in parallel with the movement, to divert the excess current around the movement (A, fig. 15). The basic meter movement generally is a microammeter or a milliammeter, and the range is extended by using a shunt.

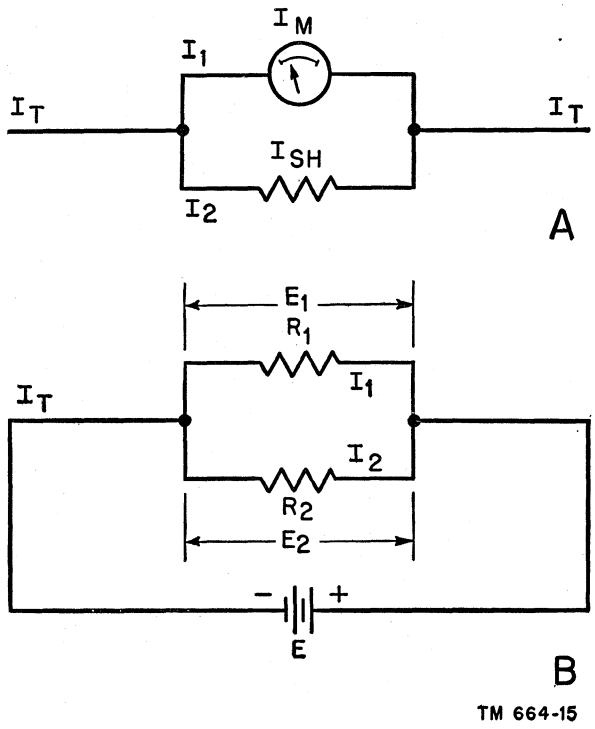


Figure 15. Current flow in a parallel circuit.

b. CURRENT THROUGH RESISTORS IN PARALLEL. In a circuit consisting of two resistors in parallel, current divides, and more current flows through the smaller resistor than through the larger one. If two resistors, R_1 and R_2, are in parallel, the voltages across both are equal, or E_1 is equal to E_2 (B, fig. 15).

Also $E_1 = I_1 \times R_1$
and $E_2 = I_2 \times R_2$.
Since $E_1 = E_2$, then $I_1R_1 = I_2R_2$.
Transposing, $\frac{I_1}{I_2} = \frac{R_2}{R_1}$.

This equation states that in a parallel circuit containing two resistors the current in each resistor is inversely proportional to its resistance. If one resistor is twice the size of the other, the current flowing through the larger resistor is one-half the current in the smaller resistor. If one resistor is three times larger than the other, only one-third of the current will flow through it. This is true because Ohm's law states that I times R must equal the same voltage when the resistors are in parallel.

c. SHUNT FORMULA.

(1) The two circuits in figure 15 show the similarity between a parallel circuit containing two resistors and a meter-and-shunt combination. The formula given in the previous paragraph can be transposed to:

$$R_1 = \frac{R_M I_2}{I_1}$$

and, since the circuits are similar, the circuit in A can be expressed:

$$R_{SH} = \frac{R_M I_M}{I_{SH}}$$

where R_{SH} is the shunt resistance, R_M the meter-movement resistance, I_M the meter-movement current for full-scale deflection (current sensitivity), and I_{SH} the shunt current. The formula now can be used to calculate the values of shunts for meter movements.

(2) It is desired to extend the current range of a 1-ma, 27-ohm movement to 10 ma. This means that a current of

10 ma will be flowing in the circuit when the needle is fully deflected (fig. 16). Since the movement can handle only 1 ma at full-scale deflection, the shunt resistance must handle the balance of the current, or 9 ma. To compute the shunt resistance necessary, the formula for R_{SH} is used.

$$R_{SH} = \frac{R_M I_M}{I_{SH}} = \frac{27 \times .001}{.009} = 3 \text{ ohms.}$$

The figure used for I_{SH} is the actual current that will flow through the shunt, which is 9 ma (total current minus meter-movement current) and not the total current (10 ma). Since the shunt is one-ninth the value of the meter resistance, there will be nine times as much current flowing through it. If the meter is connected in a circuit carrying 5 ma of current, this current will divide in a ratio of one to nine between meter movement and shunt. The current flow through the shunt will be 4.5 ma, the current flow through the meter movement will be .5 ma, and the meter needle will deflect half-scale. Since full scale represents 10 ma, then half-scale deflection represents a current of 5 ma, and all currents between 0 and 10 ma will read in proportion.

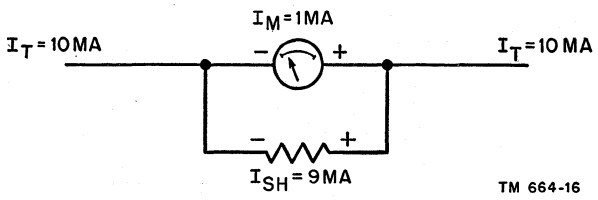


Figure 16. Extending a 1-ma movement to measure 10 ma.

(3) The internal resistance of the movement must be considered in finding the value of shunt resistance, since the value of parallel resistance depends on the value of meter-movement resistance. It is possible to ignore internal resistance only when constructing voltmeters, since large values of resistance are put in *series* with the movement, and internal resistance is negligible as compared with the multiplier resistance.

d. TYPES OF SHUNTS. In radio work, the currents measured generally are small, and meters have internal shunts. These shunts can be made of copper, nichrome, or any low-resistance conductor. Whenever the current to be measured is more than 30 amperes, the shunt usually is located outside the meter to prevent injury to the movement by heat generated in the shunt by the high current. Copper and manganin blocks are used for these low-resistance shunts, since they have a low-temperature coefficient and are capable of carrying extremely high currents. The resistance of these high current shunts is very low (much less than 1 ohm) ; the leads connecting it become part of the total shunt resistance, and any change in the length of the leads affects the accuracy of the readings.

14. Multirange Ammeter

a. MULTIPLE SHUNTS. In the multirange ammeter, it is possible to have several ranges of measurement. The meter can have a switching arrangement to change from one range to another (fig. 17), or pin jacks may be used. For example, it is desired to extend the range of a basic 0- to 10-ma ammeter to permit measurements from 0 to 10 ma, 0 to 100 ma, 0 to 1 ampere, and 0 to 10 amperes. For range 1 (0 to 10 ma), no shunt is necessary, since the movement is designed to handle 10 ma. For range 2 (0 to 100 ma), R_{SH} equals $R_M I_M / I_{SH}$ or 9 times .01/.09, or 1 ohm. For range 3 (0 to 1 ampere), R_{SH} is equal to 9 times .01/.99, or .091 ohm. For range

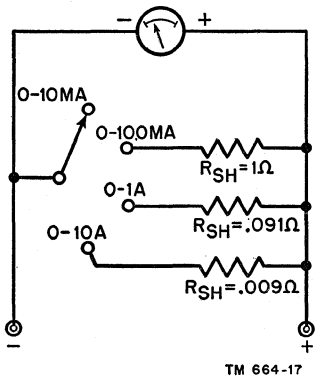


Figure 17. Multirange ammeter using separate shunts and switch.

4, 10 amperes is used to compute the shunt instead of the actual current of 9.99 amperes, because there is practically no numerical difference in the answer using either figure.

b. RING SHUNTS.

(1) Many commercial milliammeters use a tapped or ring shunt in place of separate shunts. In this arrangement, some of the resistance may be in series with the meter movement and some in parallel, depending on the range (fig. 18). For example, on the lowest range, 0 to 15 ma, all of the shunt resistors, R_1, R_2, and R_3 are in parallel with the movement, as in A. On the next range, 0 to 50 ma, R_3 is in series with the movement and R_1 and R_2 are in parallel with the movement, as in B. On the highest range, 0 to 100 ma, R_2 and R_3 are in series with the movement, and R_1 is in parallel with the movement, R_2, and R_3, as in C. Ring shunts have an advantage over separate shunts, since part of the total resistance is placed in series with the movement; therefore the parallel resistors do not have to be as low in value.

(2) To compute the values of ring shunts, the mathematical relationship between parallel resistors and current must be understood. In figure 19, R_A is 30 ohms, R_B is 60 ohms, and they are in parallel. If a total current of 3 ma is flowing in the circuit, 30/90 or one-third of the current will flow through the 60-ohm resistor (higher value in ohms) and 60/90 or two-thirds of the current will flow through the 30-ohm resistor (lower value in ohms). The current of 2 ma in the smaller resistor, R_A, is twice the amount of current flowing in R_B. There is the same ratio between one branch current and total current as there is between the opposite branch resistance and the sum of the two branch resistances (R_T). That is,

$$\frac{I_A}{I_T} = \frac{R_B}{R_T}$$

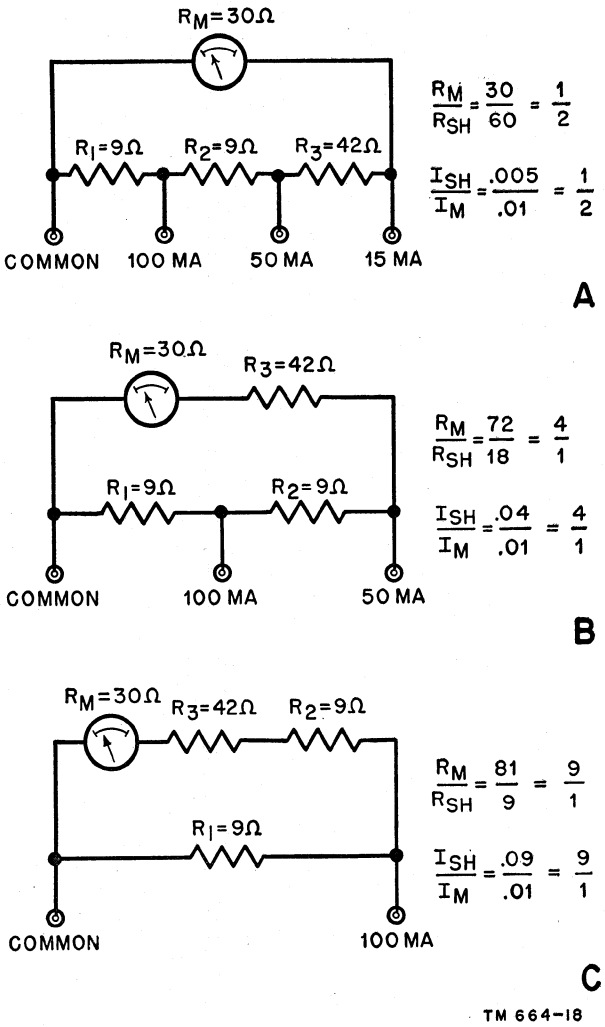


Figure 18. Ring shunt ammeter.

Where R_T is R_A plus R_B, and I_T is I_A plus I_B. This can be seen by substituting values in the equation.

$$\frac{I_A}{I_T} = \frac{R_B}{R_T} = \frac{2}{3} = \frac{60}{90}.$$

(3) Multiplying both sides by R_T, the formula becomes:

$$R_B = \frac{R_T I_A}{I_T}.$$

To use this formula for a meter shunt circuit, assume that the two parallel resistors represent a movement and a shunt resistor. Subletter *A* becomes *M* and subletter *B* becomes *SH*. The formula is then:

$$R_{SH} = \frac{R_T I_M}{I_T}.$$

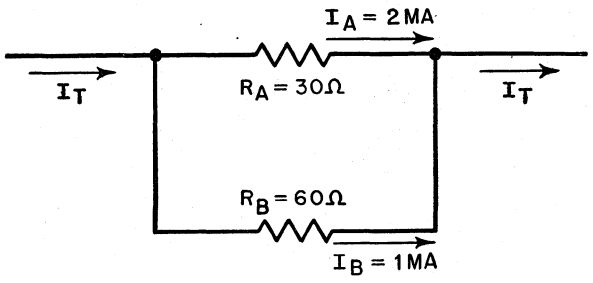


Figure 19. Computing resistance and current for a parallel circuit.

(4) To solve ring shunt problems, the value of the entire shunt resistance is found by the shunt formula R_{SH} equals $I_M R_M / I_{SH}$, and the individual shunt values in the ring are found by using the formula R_{SH} equals $R_T I_M / I_T$.

(5) For example, find the value of each resistor in the ring shunt of figure 18. The meter has a 10-ma, 30-ohm movement. First, it is necessary to find the value of the whole shunt, or R_1 plus R_2 plus R_3. On the 15-ma scale, all the resistors are in series (R_1 plus R_2 plus R_3) and act as a shunt to the meter movement. Using the old shunt formula,

$$R_{SH} = \frac{I_M R_M}{I_{SH}} = \frac{.01 \times 30}{.005} = 60 \text{ ohms.}$$

Therefore, R_1 plus R_2 plus R_3 is equal to 60 ohms. Now that the entire shunt value is known, it is possible to find R_T by computing the value of the individual resistors in the ring shunt. It should be remembered that R_T means the sum of the entire shunt plus the internal resistance of the movement. Since the entire shunt is 60 ohms and the internal resistance of the movement is 30 ohms, R_T is equal to 90 ohms. The value of the shunt for the highest range (0 to 100 ma), can now be computed. For this range, as in C, R_1 acts as the shunt. Using the ring-shunt formula,

$$R_1 = \frac{R_T I_M}{I_T} = \frac{90 \times .01}{.1} = 9 \text{ ohms.}$$

For the 50-ma range, the shunt is R_1 plus R_2, as in B, and

$$R_1 + R_2 = \frac{R_T I_M}{I_T} = \frac{90 \times .01}{.05} = 18 \text{ ohms.}$$

Since R_1 is 9 ohms and R_1 plus R_2 is 18 ohms, it is obvious that R_2 must be 9 ohms. Then, R_3 must be the difference between 60 ohms and 18 ohms, or 42 ohms.

15. High-Resistance Meter

a. When a low-resistance voltmeter is used to measure the voltage across a high value of resistance, circuit conditions may be upset and cause inaccurate readings. For example, in A of figure 20, two 100,000-ohm resistors are in series across a 60-volt battery. Since the resistances are equal, there must be 30 volts across each one.

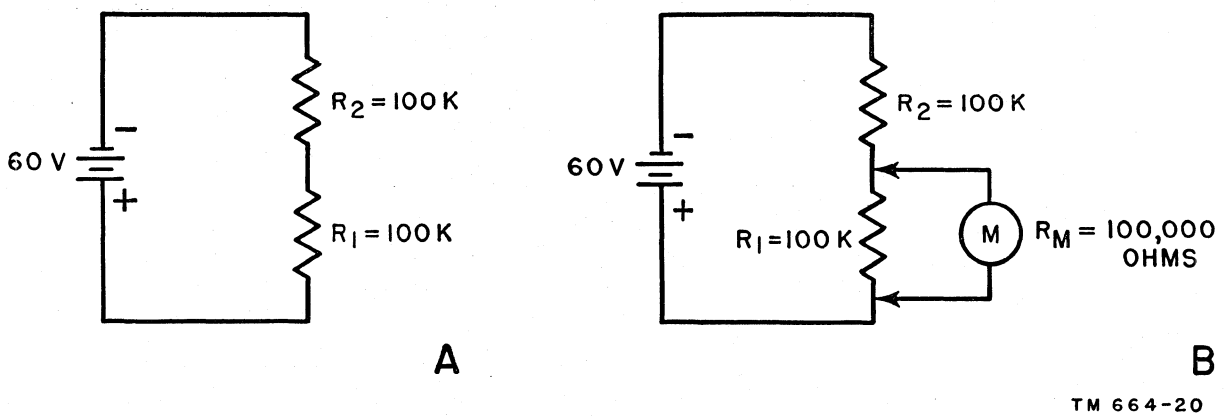


Figure 20. Low-resistance meters in high-resistance circuits give inaccurate voltage readings.

b. Suppose a 1,000-ohms-per-volt meter is placed across R_1, with the meter on the 100-volt scale, as in B. Then 100,000 ohms of resistance are in series with the meter (1,000 ohms per volt times 100 volts). When the meter is placed across R_1, two 100,000-ohm resistors are in parallel and the combined value becomes equal to 50,000 ohms. As a result of this change in resistance, the voltage distribution in the circuit changes. The total circuit resistance is now 150,000 ohms instead of 200,000 ohms. Because R_2 now has two-thirds of the total resistance in the series circuit, 40 volts, or two-thirds of the total voltage, appears across R_2, and only 20 volts appears across the combination of R_1 and the meter. The meter always reads the voltage across itself, and this is 20 volts, but as soon as it is removed, the voltage across R_1 changes back to 30 volts. *Placing a comparatively low-resistance voltmeter in the circuit may upset circuit conditions, leading to inaccurate readings.*

c. When a more sensitive meter with a higher value of multiplier resistance is used, the reading is more accurate. A 20,000-ohms-per-volt meter on the 100-volt range has 2,000,000 ohms of resistance in series with the meter movement (20,000 ohms per volt times 100 volts is equal to 2,000,000 ohms). When a 2,000,000-ohm resistor is placed in parallel with the 100,000 ohms of R_1, the combined parallel value of resistance remains 100,000 for all practical purposes. Therefore, no voltage redistribution takes place when the meter is connected across R_1, the voltage remains 30 volts, and the meter reads accordingly.

d. The higher the sensitivity of the movement, the more multiplier resistance it has for a given range, and consequently, the less it can upset circuit conditions when voltages are measured. When only a low-resistance meter is available to take voltage readings in high-resistance circuits, the shunting effect of the meter must be accounted for. The shunting effect can be reduced by taking a reading on the highest practical range of the meter, even though the deflection obtained is not great. The added resistance of the meter causes less redistribution of voltage and reduces the inaccuracy of the reading.

16. Meter Applications

a. Another method for measuring voltages higher than the meter can handle is to build a voltage divider with 10 resistors of the same value in series. The values of these resistors should be at least 1 megohm so that little current is drawn from the load. This divider then is connected across the voltage to be measured, and a reading is taken across one resistor of the divider. The total voltage is 10 times the actual reading of the meter, because the 10 resistors are equal in value and the meter measures one-tenth of the entire value.

b. Unlike the voltmeter, the ammeter should have low resistance to prevent changing circuit operation. If an ammeter is inserted in a circuit where the total resistance is small, it reduces the current flow appreciably. When the ammeter resistance is small in comparison with the series resistance in the circuit, however, it has a negligible effect on the total current, and the meter reading is accurate. In trouble shooting, the technician seldom takes current readings, since this involves opening a circuit. Sufficient information usually can be obtained by taking voltage and resistance readings to find the source of trouble. When necessary, the current may be computed by measuring the voltage and resistance, using Ohm's law to find the current. If a current reading is desired, and a suitable ammeter is not available to make the reading, usually it is simpler to find the current by the voltage method than to make a shunt of the required value. Connect a small resistor of known value in series with the circuit and measure the *voltage* across the resistor. Then compute the current by Ohm's law. The resistance inserted in the circuit must be small (less than one-tenth of the series resistance in the circuit), or inaccurate readings result.

17. Precautions in Using Voltmeter and Ammeter

a. Since an ammeter has a low resistance, it is important to be especially careful in using it. If mistakenly put across a voltage source, the meter can be damaged. Never connect an ammeter or milliammeter *across* a battery or resistor. Always break the circuit and connect

the meter in *series*, one meter lead going to each point of the circuit break.

b. Connect voltmeters in parallel or across the circuit component being measured.

c. When using either ammeters or voltmeters:

(1) Always start at the highest meter range when measuring an unknown quantity. Then drop down to a lower range if necessary. This practice protects the meter from injury which may result if an attempt is made to read a high value in a low range.

(2) *Observe polarity.* Test leads usually are color-coded—black for negative and red for positive. Place them in their proper pin jacks.

18. Summary

a. The moving-coil meter is popular in radio and electrical work because it is accurate, rugged, and has a linear scale.

b. The main parts of the moving-coil meter are:

(1) A strong horseshoe permanent magnet with soft-iron pole pieces.

(2) A circular air gap which produces a uniform radial magnetic field.

(3) A coil wound on a rectangular aluminum frame with indicating needle attached.

(4) Hard-steel pivots in jeweled bearings supporting the coil assembly.

(5) Two light, spiral springs, oppositely wound, to compensate for temperature changes.

(6) An adjusting screw for zero-adjust of the meter.

(7) A very light moving-coil assembly, since very small currents are required for full-scale deflection.

c. Three systems are involved in the operation of a meter: motor, control, damping.

d. The motor system of moving-coil meters depends on the current flowing through a coil and magnetizing it. The coil then is repelled by a permanent magnet in proportion to the amount of current passing through the coil.

e. A control system consists of two oppositely wound springs that control the amount of deflection, bring the coil back to 0, conduct current to and from the coil, and compensate for temperature changes.

f. A damping system brakes the pointer swing. This is accomplished by:

(1) Eddy currents in the aluminum frame setting up an opposing field as the coil moves.

(2) A counter emf in self-supporting coils which are used only as ammeters.

g. The accuracy of the meter movement is expressed in percentage of full-scale deflection.

h. The internal resistance of a meter is the amount of d-c resistance in the coil assembly.

i. Sensitivity of meter movements can be expressed in two ways: In amount of current needed for full-scale deflection, and in ohms per volt—that is, the number of ohms which must be put in series with the meter to measure 1 volt.

j. Meter movements can measure only small currents directly. Their circuits can be modified to measure a large range of voltages or currents. To use a movement as a voltmeter, a large resistance is placed in series with it. To use it as an ammeter, a small resistance is placed in parallel with it.

k. The high values of resistance in high-resistance voltmeters (meters with high sensitivity) upset circuit conditions less, and therefore, give more accurate voltage readings in radio circuits.

l. The following precautions are necessary in using meters:

(1) Never connect an ammeter across a battery or a resistor; always connect it in series with them. The circuit must be broken to connect an ammeter in it.

(2) Connect voltmeters in parallel with the component to be measured.

(3) For both types of meters, observe polarity. Start with the highest range, and go down, if necessary, to get a readable scale deflection.

19. Review Questions

a. Draw a simplified drawing of a moving-coil meter and label the important parts.

b. With reference to the moving-coil meter, define and describe the motor system, the control system, and the damping system.

c. Explain what is meant when a meter is said to be accurate within 2 percent.

d. Define: (a) sensitivity of a meter movement, (b) internal resistance of a meter.

e. Can an unmodified moving-coil movement be used in general radio work? Explain.

f. Using a 500-μa, 55-ohm movement, compute the resistor values of a 5-range voltmeter, using the following ranges: 5 volts, 50 volts, 125 volts, 500 volts, and 1,000 volts.

g. Compute the resistor values of a 4-range voltmeter with a 5-ma, 12-ohm movement. Ranges: 10 volts, 100 volts, 250 volts, and 500 volts.

h. Using a 2-ma, 18-ohm movement, compute the resistor values of a 4-range ammeter using separate shunts. Ranges: 2 ma, 10 ma, 100 ma, and 1 ampere.

i. A ring-shunt milliammeter is to be constructed, using a 1-ma, 27-ohm movement. Ranges: 1.5 ma, 10 ma, and 20 ma. Find the resistor values.

j. What is the effect of using low-resistance voltmeters across high-resistance circuits? Explain.

k. Outline precautions to be observed when using d-c meters.

SECTION III

A-C AMMETERS AND VOLTMETERS

20. Low-Frequency A-C Meters

Three types of meters are used widely for measuring low-frequency ac: The repulsion-type moving vane, which measures either ac or dc, but is relatively insensitive; the copper-oxide rectifier, which changes the ac to dc and then measures the rectified dc on a sensitive meter suitable for measuring dc only; and the vtvm, which uses vacuum tubes to amplify the a-c voltage and then measures the change in d-c current produced in the plate circuit of the vacuum tube by the a-c voltage being measured. Before discussing these meters in succeeding paragraphs, a brief review of some a-c definitions is offered as an aid to the understanding of how ac is measured.

a. NATURE OF AC. Alternating current flows periodically first in one direction and then in the opposite direction, as shown in figure 21. The time necessary for the current to go from 0 to a maximum positive, to 0, to maximum negative, and return again to 0 is the time for 1 cycle. That portion of the cycle during which the current flow is in one direction only, as in B, is called an alternation. Frequency is the number of cycles occurring per second and an alternating current may be any frequency.

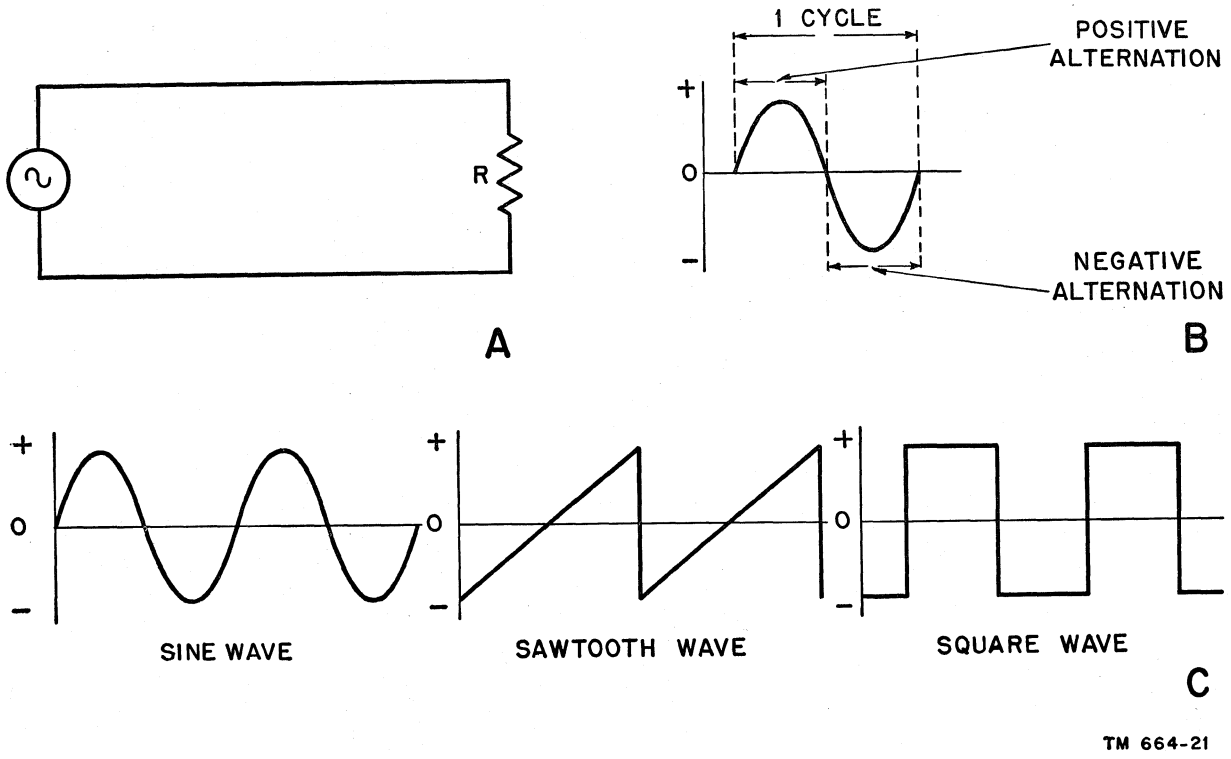


Figure 21. Fundamental a-c ideas.

b. WAVESHAPE. The waveshape is a graphical picture of current or voltage, varying in relation to time. The graphs in C show instantaneous values of amplitude and direction at any instant. Sine waves, square waves, and sawtooth waves are a few of the many forms an a-c wave may take.

c. RMS VALUE OF SINE WAVE.

(1) The mathematical average of an a-c sine-wave cycle is 0, since the positive and negative halves of the cycle are equal. The words *positive* and *negative* are convenient labels to indicate that the current changes direction, but, from the standpoint of circuit operation, current flows during both halves of the a-c cycle and accomplishes as much work in one direction as in the other. When current follows a sine-wave pattern, its amplitude is changing constantly during each alternation and the problem in measuring ac is this: The fundamental electrical units, the volt and the ampere, are based on dc. How do the constantly changing values of voltage and current in a sine wave compare with dc? It cannot be the peak value, for example, since the sine wave reaches the peak value for only an instant during each alternation.

(2) To obtain a relationship between ac and dc, the heating effects of both were studied. It was found that a current or voltage equal to .707 of the peak a-c amplitude produced in a given value of resistance the same heating effect as an equal amount of dc. For example, a circuit has sine waves of ac with a peak value of 5 amperes flowing through it. This current has a heating effect equal to .707 of 5, or 3.535 amperes of dc, and is called the *rms* (root mean square) or *effective* value:

$$I_{eff} = .707\ I_{max}$$

$$I_{max} = \frac{I_{eff}}{.707} = 1.414\ I_{eff}.$$

(3) The heating effect of current is based on the power formula, P equals I^2R, which determines the power dissipated in the form of heat. This heat varies as the square of the current, and when the sine wave reaches its peak value, the heat becomes maximum (the peak value of current squared times the resistance). To find the amount of heat dissipated in the circuit during the entire sine-wave cycle, each instantaneous value of current is squared, and a mean, or average, of the sum of these values is found, and the square root taken. The value obtained is the effective or rms value and corresponds to .707 of the peak value.

d. A-C METERS CALIBRATED IN RMS. A-c meters are calibrated so that they read the rms value of the sine wave of voltage or current being measured. When an a-c meter reads 70.7 ma, for example, a sine wave of current with a peak value of 100 ma is being measured.

e. AVERAGE VALUE AND FORM FACTOR. Two other values of the sine wave are important in understanding how meters are calibrated: The average of the instantaneous values of current during one alternation is taken, and it is found that

$$E_{ave} = .637\ E_{max}.$$

The effective value is, therefore, larger than the average value by

$$E_{eff}/E_{ave} = .707/.637 = 1.11.$$

The factor 1.11 is known as the *form factor* for a sine wave, and is the ratio of the effective voltage to the average voltage. The effective and average values given apply *only to sine waves* of current and voltage.

21. Moving-Vane Meters

The only moving-iron meters used today are of the moving-vane type. Although these meters measure either ac or dc, they usually are used exclusively for a-c measurements because more sensitive and more accurate instruments are available for dc. However, moving-vane meters can be used for measuring low-frequency voltages and current.

a. BASIC MOTOR SYSTEM.

(1) *Repulsion of iron vanes.* The motor system of moving-vane meters is based on the principle that two soft-iron

vanes repel each other when magnetized with the same polarity (fig. 4). The vanes are placed inside a coil, and the coil becomes an electromagnet when current is allowed to flow. Lines of force leave the north pole of the coil, bend around the outside in all directions, and re-enter the coil at the south pole. Within the coil, many lines of force pass through the iron vanes, since the iron has a lower reluctance than the air. As a result of these lines of force going through the iron vanes, flux lines at the top and bottom of the vanes are close together. This concentration of lines of force in the same direction causes the vanes to move away from each other. On the next alternation of current the vanes also repel each other, because the polarity of the coil reverses when the current reverses. The polarities of both vanes reverse at the same time and, even though reversed, they still repel. The *radial-vane* and the *concentric-vane* meters use this motor system.

(2) *Radial-vane meter.* In the radial-vane meter, a rectangular iron vane is placed inside the coil. One is fixed in position; the other has a pointer attached and is free to move on its pivots (fig. 5). These pivots fit in jewelled bearings and allow the vane to turn with a minimum of friction. When current flows through the coil, the rectangular vanes become magnetized and repel each other. The moving vane swings away on its pivots, and the attached needle indicates the strength of the current passing through the coil.

(3) *Concentric-vane meter.* The concentric-vane meter differs somewhat from the radial-vane meter in construction, although it follows the same general principles of operation. The soft-iron vanes are semicircular (fig. 6) and are called concentric because one vane is inside the other. The fixed vane is outside and tapered at one edge, and the inner vane is pivoted and has square edges. When current flows through the coil, lines of force pass through both vanes. The lines of force through the movable inner vane are distributed evenly; the fixed vane has a tapered edge and the concentration of flux lines is not uniform. Fewer lines pass through the tapered point than through the rest of the vane because it has less iron and more reluctance. The crowded lines of force repel each other and the movable vane is forced to swing in the direction that will redistribute the lines until there is maximum space between them. This means that the movable vane swings in the direction in which the tapered vane is pointing, since there are fewer lines of force in that direction. The amount of swing depends on the strength of current flowing through the coil and the control action of the springs.

b. CONTROL SYSTEM. Both radial-vane and concentric-vane meters have springs to provide control action (fig. 22). The springs provide the correct amount of opposition to the swing of the movable vane. They also serve to bring the pointer back to 0 when the meter is removed from the circuit. The needle registers at the point where the repelling force of the vanes equals the counterpull of the springs.

c. DAMPING SYSTEM. In small radial-vane meters, the coil is inclosed in a metal container and the moving vane fits snugly in the space. As the moving vane is repelled, it compresses the air in front of it and its speed of travel to the indicating position is decreased. When the needle comes to a stop, there is no further damping or braking action. In larger meters, a light aluminum damping vane is attached to the same rod as the pointer and moving vane (fig. 22). The damper vane then is inclosed in a separate, air-tight damping chamber and the damping action is very efficient.

22. Additional Characteristics of Moving-Vane Meters

a. SCALE CALIBRATION.

(1) *Square-law scale.* The concentric-vane

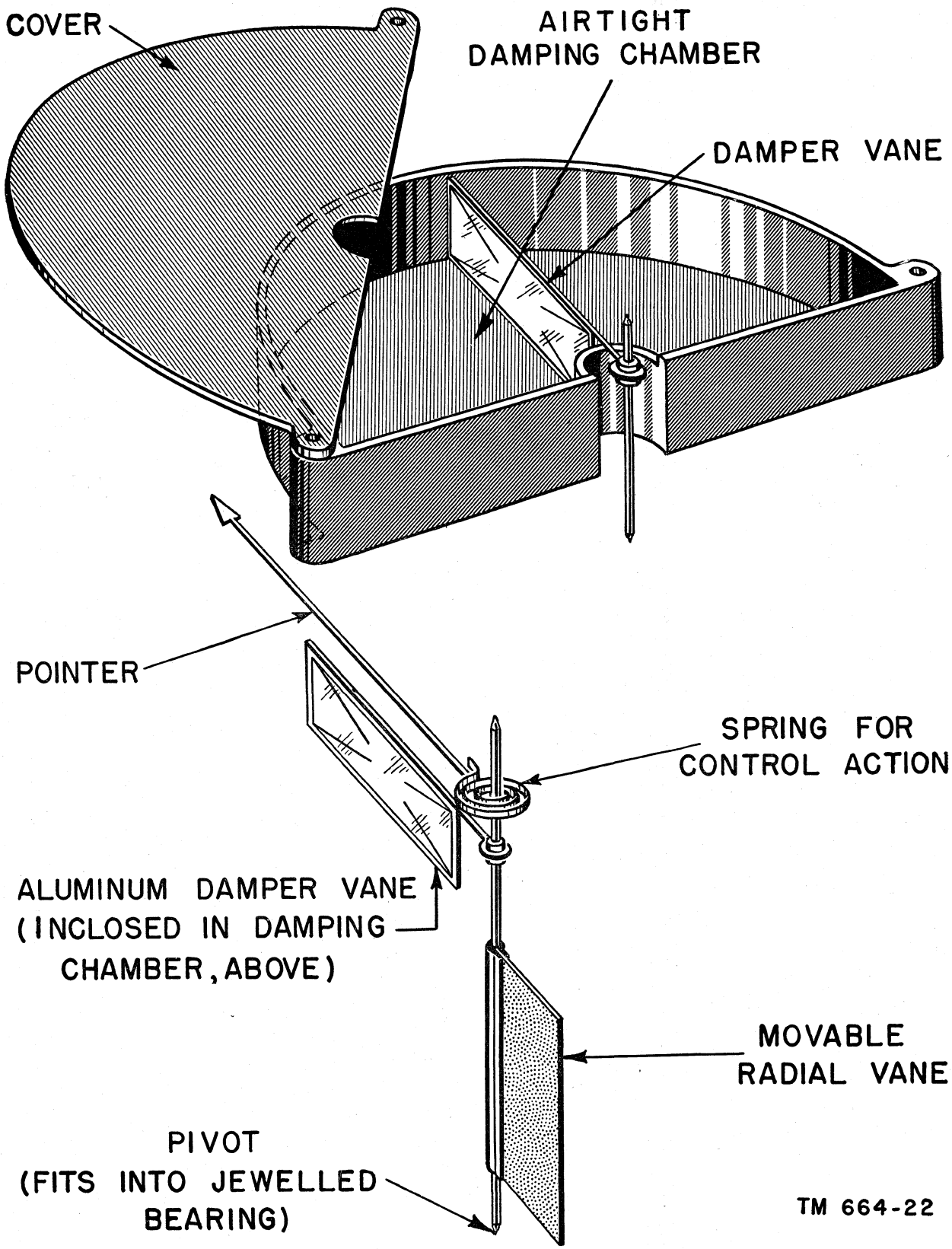


Figure 22. Air-damping system used in moving-vane meters.

causes the pointer to indicate according to the square law rather than in direct proportion to the amount of current flow. For example, if the current is doubled, the magnetic field around each vane is twice as strong. Since each vane repels twice as much, the combined repulsion of the two vanes is four times as great. The repulsion and the pointer swing *do not vary directly* with the current; they vary as the *square* of the current. Doubling the current results in four times the deflection, tripling the current results in nine times the deflection, and so on. Deflection is, therefore, said to be square law and the scale is nonlinear, with the numbers on the low end of the scale crowded together and the numbers on the high end spread farther apart. In a true square-law scale, any point on the scale which represents twice the value of a point lower on the scale also represents four times the deflection. For example, figure 23 shows full-scale deflection as 10 and quarter-scale deflection is 5. Doubling the current gives four times the deflection.

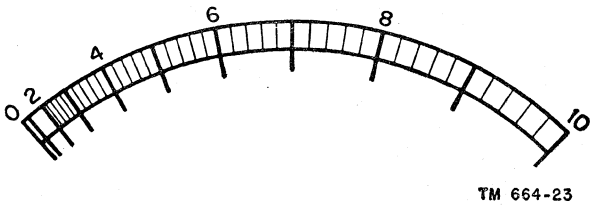


Figure 23. Square-law scale.

(2) *Calibration in rms values.*

(*a*) When a sine wave of current passes through the coil, the current is not steady but is changing constantly. If 60 cps is being measured, current through the coil goes from 0 to peak value to 0 in one direction, then does the same in the opposite direction, 60 times per second. The lines of force are continually changing in strength as well as direction. The amount of repulsion the vanes have for each other, therefore, varies from 0 to maximum to 0 120 times per second, since they repel each other on both halves of the cycle.

(*b*) The meter needle remains steady at one position because the iron vanes have so much inertia they cannot follow the instantaneous changes of flux. It is physically impossible for them to change position 120 times per second. The vanes, therefore, take a position based on the average value of lines of force present over each alternation. This depends on the average value of current, which is .637 times the peak value, and the meter needle indicates this value of current.

(*c*) To have any meaning, a-c measurements must be in terms of *rms*, or the heating equivalent of dc. For this reason, the markings on the scale are in terms of the rms value, rather than the average value, of the sine wave. For example, a scale is being designed for a new meter. A sine wave of voltage with a peak value of 100 volts is placed across the meter and the needle registers the average value, or 63.7 volts. This position of the needle then is marked with the effective value, or 70.7 volts (E_{eff} equals .707 times 100, or 70.7 volts) and the rest of the scale is calibrated in the rms rather than the average value.

(3) *Sine-wave calibration.* Most a-c meters are calibrated on the basis of a 60-cps sine wave. However, not all of the ac found in radio circuits has a sine-wave shape. *When an a-c meter is used to measure nonsinusoidal voltages and currents, an approximate indication of values is obtained and not exact information.*

b. FREQUENCY RESPONSE. Moving-vane meters generally are not used to measure ac above 100 cps since most of them are calibrated on the basis of a 60-cps sine wave. The inductive reactance of a coil (X_L equals $2\pi fL$) increases with frequency and causes a reduction in the current flowing through it. Owing to

this increased reactance, when moving-vane meters are used to measure frequencies higher than the usual line frequency, inaccurate readings result. Core losses (hysteresis and eddy-current losses) also increase in the iron vanes at higher frequencies and introduce comparatively large power losses in the circuit being measured.

c. ACCURACY. Most moving-vane meters have a rated accuracy of plus or minus 5 percent.

d. ZERO-ADJUST. The screw in the front of the case moves the spring and permits the pointer to be adjusted to 0.

e. IRON CASE. Magnetic shielding is used to prevent outside magnetic fields from influencing the meter readings. This is accomplished by inclosing the meter in an iron case.

f. USE AS VOLTMETER AND AMMETER. For use as a voltmeter, the coils of the moving-vane meter are wound with many turns of fine wire and multiplier resistors can be used as needed to increase the range. For ammeter use, the coils have fewer turns and larger wire is used. Moving-vane meters can be used to measure fairly high currents without the use of shunts. However, because of their low sensitivity, they cannot measure small currents as well as the moving-coil meter. The highest sensitivity available is about 15 ma, which corresponds to 67 ohms per volt. Moving-vane meters are useful for measuring voltage and current at line frequencies, but because of their low sensitivity they generally are not used in circuit testing.

23. Copper-Oxide Rectifier Meter

In circuit testing, most low-frequency a-c measurements are made with either a copper-oxide rectifier meter or a vtvm. The copper-oxide rectifier meter is more sensitive and more accurate than the moving-vane meter, but not as sensitive as the vtvm. It often is a part of a multimeter, which also is used to measure direct current, d-c voltage, and resistance.

a. COPPER-OXIDE RECTIFIER CONSTRUCTION. The copper-oxide rectifier meter is a combination of a d-c moving-coil meter (d'Arsonval movement) and a copper-oxide rectifier. The ac is rectified and the pulsating dc then is measured by the d-c meter. The copper-oxide rectifier consists of several copper disks with each disk having a layer of copper-oxide on one of its sides. Lead washers separate the disks, and they are clamped together under pressure. The disks can be arranged to provide either half-wave or full-wave rectification (fig. 24).

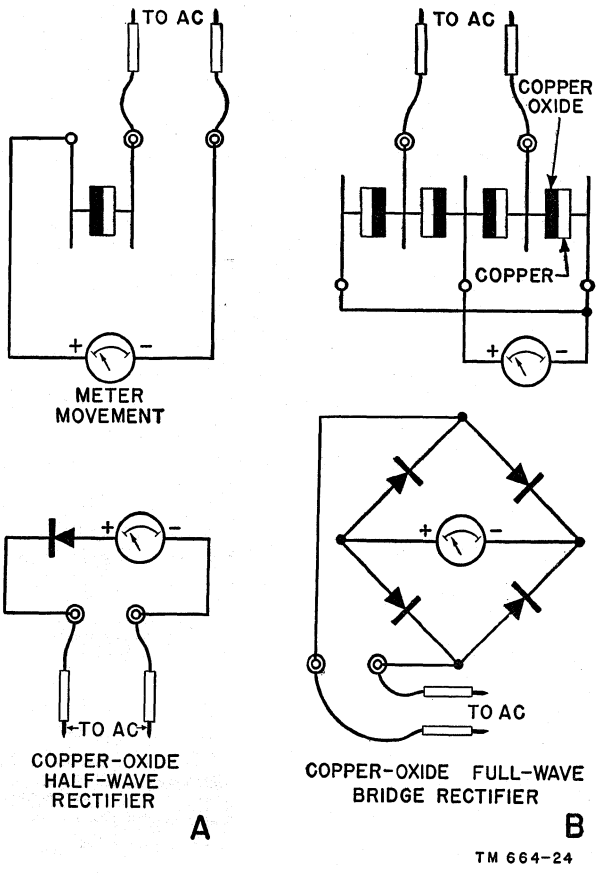


Figure 24. Copper-oxide rectifiers, half-wave and full-wave.

b. RECTIFIER ACTION. The function of a rectifier is to change ac to a form of dc. This means that the current from the output of the rectifier does not reverse its direction. It allows current to pass readily in one direction through the circuit but not in the reverse direction.

(1) *Unidirectional conduction.* The resistance to the current flow from the copper to the copper-oxide is very low compared with the resistance in the reverse direction. Because of this, the current flow is said to be unidirectional and this device can be used as a rectifier.

(2) *Half-wave rectification.* When ac is applied to a rectifier in series with a resistor (A, fig. 25), current passes through the rectifier from the arrowhead to the flat side, but not in the opposite direction. The current through the resistor is not reversing its direction and is no longer ac, but pulsating dc. In half-wave rectification, current flows through the resistor during one alternation of each cycle, but not during the other.

(3) *Full-wave rectification.* Current can be made to flow through the resistor in the same direction during both halves of the a-c cycle by using the bridge rectifier circuit shown in B of figure 25. When the positive alternation is applied to rectifier 1, current flows from the generator through rectifier 2, resistor *R from left to right,* rectifier 1, and back through the generator. On the next alternation, the polarity of the generator reverses. Current then flows from the generator through rectifier 4, resistor *R from left to right,* rectifier 3, and back through the generator. The current flows through the resistor in the same direction on both alternations. The ac from the generator becomes pulsating dc—pulsating because the current is not steady in value and dc since the

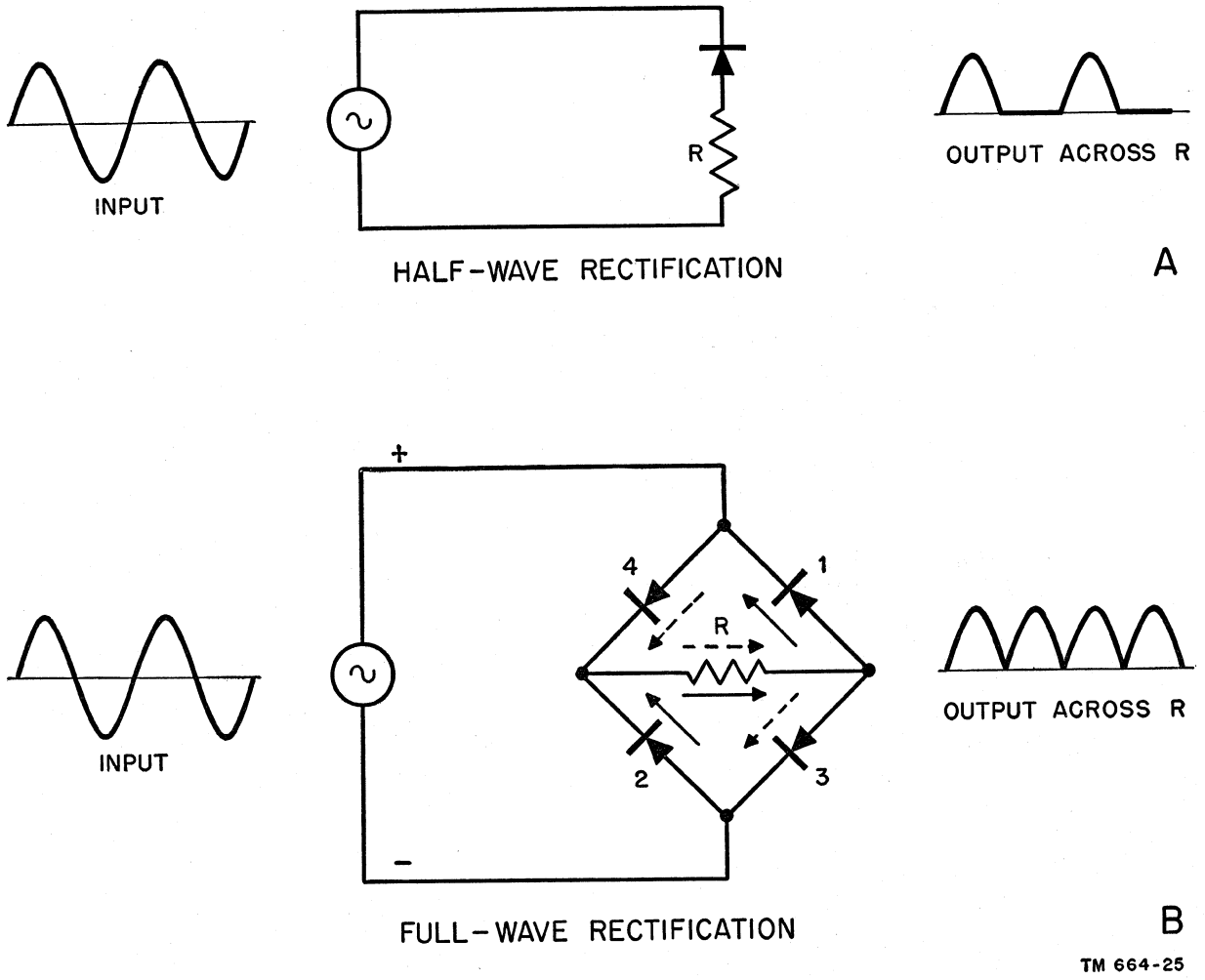


Figure 25. Half-wave and full-wave rectification.

current through the resistor is not changing direction.

c. USE OF D-C METER AND RECTIFIER.

(1) It is possible to measure ac by substituting a d-c movement for either resistor in figure 25. The ac to be measured is changed to pulsating dc by rectifier action, and then passes through the meter coil, allowing the pointer to read the average current. The moving coil cannot follow the instantaneous changes of pulsating dc because of its inertia.

(2) The average current through the coil during full-wave rectification differs from that produced by half-wave rectification. In full-wave rectification, the average current is .637 of the peak value, since both halves of the a-c wave are being used. The pointer, therefore, takes a position corresponding to .637 of the peak value of the current flowing through the meter. The scale, however, is calibrated to read in rms values, or .707 of the peak current being measured.

(3) In half-wave rectification, current flows through the meter during one alternation but not on the other. Because of its inertia, the coil cannot follow all of the instantaneous changes of current over the *whole cycle*. The average current for one alternation is .637 of the peak value, but for the next alternation it is 0. Therefore, the average current for the whole cycle is the sum of both alternations divided by two.

(4) The average current for the whole cycle is (.637 minus 0)/2, or .318 of the peak value. The needle takes a position representing .318 of the peak value of current flowing through it. This point, however, is calibrated at .707 of the peak value, so that the meter reads the rms value of the ac being measured.

d. PRACTICAL RECTIFIER-METER CIRCUIT.

(1) To take voltage readings, multiplier resistors must be placed in series with the meter movement and a copper-oxide rectifier. When this is done, the efficiency of the rectifier is reduced, since no rectifier can be perfect and there must be some resistance. The resistance of the rectifier while conducting, known as the forward resistance, is small. However, the back, or leakage, resistance is not infinite but has a definite value, about 50 times greater than the forward resistance.

(2) For example, assume that a meter movement with 50 ohms resistance is placed in series with a rectifier that has a forward resistance of 1,000 ohms. Within the meter, there is now a total of 1,050 ohms of resistance in one direction and 50,050 ohms in the other, since the back resistance is 50 times the forward resistance. Current for all practical purposes flows in one direction only through the meter (A, fig. 26). Assume that the voltage being measured is large and it is necessary to place 100,000 ohms of multiplier resistance in series with the meter and the rectifier, as shown in B. On one alternation, the total resistance to current flow comprises the multiplier resistance, R, or 100,000 ohms, the forward resistance of the rectifier, R_f, or 1,000 ohms, and the meter-movement resistance, R_m, or 50 ohms. The total resistance is then R plus R_f plus R_m, or 101,050 ohms. On the next alternation, the rectifier does not conduct and the total resistance is 150,050 ohms, since the rectifier resistance, R_b, is now 50,000 ohms (B, fig. 26).

(3) There is little difference in the amount of resistance on each alternation—101,050 ohms in the forward direction compared with 151,050 ohms in the opposite direction. There is almost as much current flowing through the meter movement in one direction as in the other. Consequently, there is only a small deflection of the meter based on the difference between the currents flowing during the two alternations.

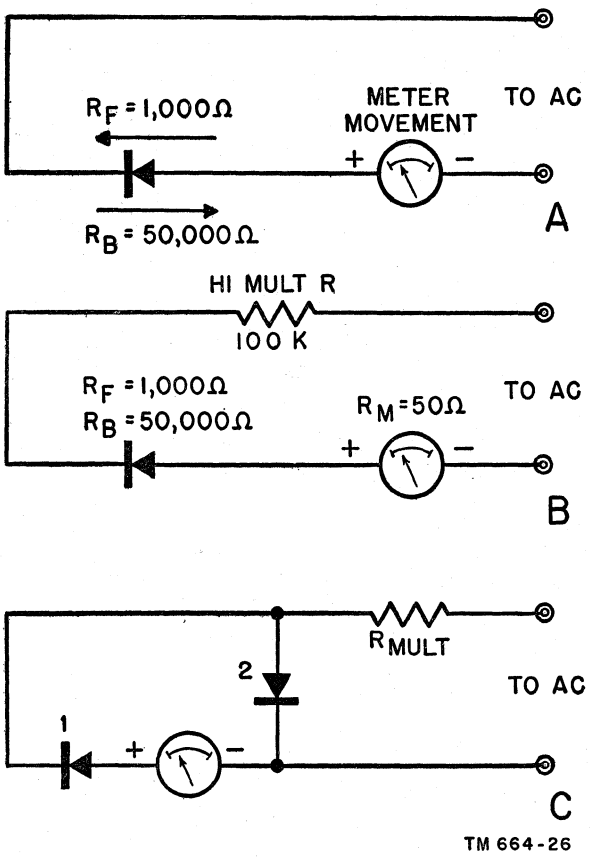


Figure 26. Double half-wave rectifier circuit cuts out loss of rectifier efficiency.

(4) To overcome the inefficient rectification caused by putting a large multiplier resistance in series with the rectifier, a double half-wave circuit generally is used (C, fig. 26). On one alternation, half-wave rectification occurs and current flows through the meter movement and rectifier 1; on the other alternation, current flows through rectifier 2 and bypasses the meter movement and rectifier 1.

e. ADDITIONAL DESIGN REQUIREMENTS.

(1) The forward resistance of a copper-oxide rectifier varies with the amount of current flowing through the rectifier, and also varies somewhat in different rectifier units. To compensate for this, the meter circuit must be properly designed or the calibration of the meter will be upset.

(2) Since the forward resistance can vary from 2,000 to 500 ohms as current through the rectifier varies from .1 ma to 1 ma, the calibration of the meter is nonlinear. When a shunt is placed across the meter movement, and both shunt and movement are placed in series with the rectifier (fig. 27) this difficulty is partially overcome.

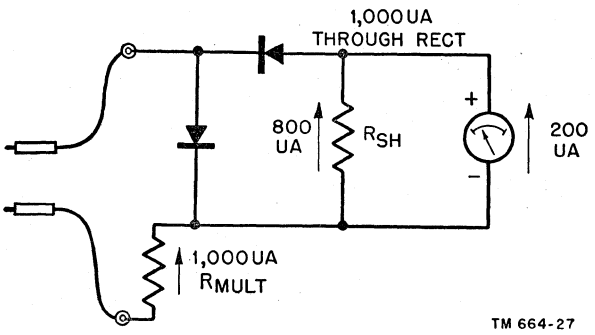


Figure 27. Shunt across meter movement increases current through rectifier but decreases meter ohms-per-volt rating.

(3) For example, if the movement has a sensitivity of 200 μa and the shunt has one-fourth the resistance of the meter movement, then four times as much current will flow through the shunt. When the meter is deflected full scale, 800 μa flows through the shunt, 200 μa through the meter, and a total of 1,000 μa, or 1 ma, flows through the rectifier. Even at low meter readings, a substantial amount of current flows through the rectifier when a shunt is used and the change of rectifier resistance is small.

(4) However, since there is now 1 ma of current flowing through the multiplier resistors at full-scale deflection, the meter effectively has a 1-ma movement instead of a 200-μa movement. Multimeters that have a different ohms-per-volt rating for ac than for dc are common, and in most multimeters the a-c meter is rated at 1,000 ohms per volt.

(5) With a proper choice of shunt values, the scale is more nearly linear and the same set of numbers on a multimeter

scale can be used for ac or dc. Multimeters often have separate scale markings to be used for a-c readings and provide separate scale calibration as well as separate numbers for a-c measurements (fig. 28).

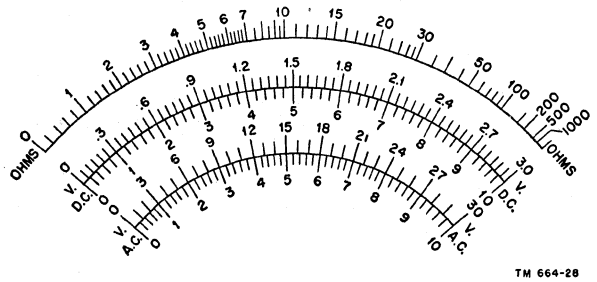


Figure 28. Typical multimeter scale. The a-c volts scale has separate calibration and separate numbers.

(6) Meter circuits can include one or more variable resistors to compensate for rectifier variations when the rectifier unit is changed (R_1 and R_2 in fig. 29). A known a-c voltage is applied and the resistors are varied until the voltage is measured correctly on the scale, and the meter then is said to be calibrated.

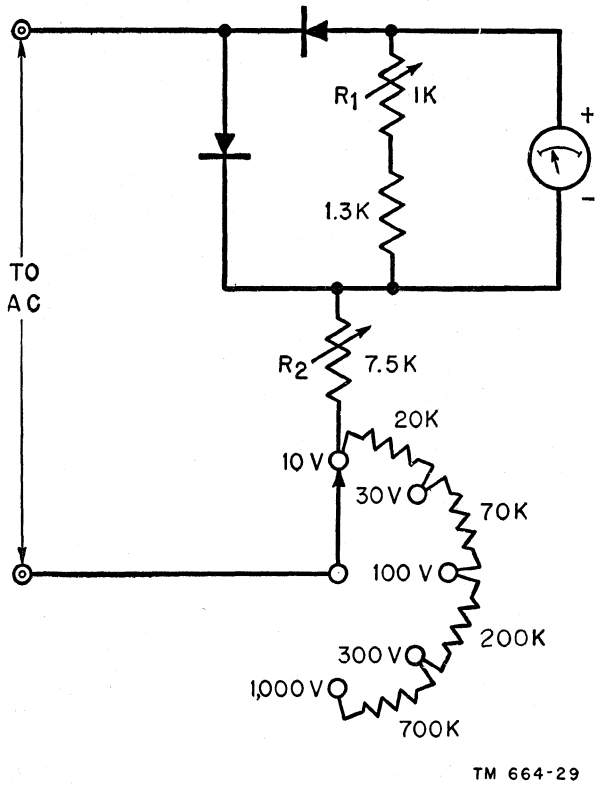


Figure 29. Typical commercial circuit of copper-oxide rectifier meter, 1,000 ohms per volt.

24. Rectifier Characteristics of Copper-Oxide Rectifier Meters

a. RECTIFIER QUALITIES. Copper-oxide rectifiers can last for a long period when not overloaded, but when operated at temperatures above 160° F. they deteriorate rapidly. A typical unit with an area of three-sixteenths inch can handle up to 15 ma of current and has a breakdown voltage of about 11 volts per unit.

b. METER ACCURACY. Since the rectifier inaccuracy adds to the inaccuracy of the moving-coil meter, the over-all accuracy of the meter is usually within 5 percent.

c. FREQUENCY RESPONSE. When the frequency being measured increases, the readings become progressively lower. This is caused by the capacitance (approximately .009 μf) of the copper-oxide rectifier unit. As the frequency increases, the capacitive reactance of the rectifier decreases and acts as a low-resistance path across the rectifier. The readings become one-half to 1 percent lower per 1,000 cps (cycles per second) up to 35 kc (kilocycles). Because of this, these meters generally are not used to measure frequencies above the audio range (15,000 cps). For example, if a 5,000-cps voltage is measured, the meter reads from 2½ to 5 percent low depending on the instrument used.

d. SCALE. The scale tends to be slightly nonuniform at the low end because the forward resistance of the rectifier varies with the current flowing through it.

e. USE AS VOLTMETER AND AMMETER. The copper-oxide rectifier meter can be used either as a voltmeter or an ammeter, but is more commonly used as a voltmeter for low-frequency a-c voltage measurements. Rectifier meters are more sensitive and, therefore, upset circuits less than moving-vane meters do.

25. Comparison of A-C and D-C Meters

a. A-c meters are calibrated to the rms value of a sine wave, although they respond to the average value. When an a-c meter is placed across dc, it reads high by at least 1.11 (form factor) times the voltage being read, but when a d-c meter is placed across ac, it does not regis-

ter at all. The needle of the d-c meter does not move back and forth in step with the changing current because of the inertia of the movement, but remains at 0 and quivers slightly. This does not mean that current is not flowing through the meter. A d-c meter on a low range, placed across a high a-c voltage, can be damaged, even though the needle does not move.

b. It is not necessary to observe polarity when using a-c meters, since the polarity of the voltage is always changing.

c. When nonsinusoidal alternating currents are to be measured, it is necessary to check not only the amplitude, but also the waveshape and the frequency of the ac. Therefore, other instruments, such oscilloscopes, generally are used to measure the amplitude, waveshape, and frequency of nonsinusoidal waves.

26. Summary

a. MOVING-VANE METERS.

(1) Two moving-iron meters are used in electrical work, the radial-vane and the concentric-vane.

(2) The motor system of moving-vane meters works on the principle of two soft-iron vanes, inside a current-carrying coil, becoming magnetized and repelling each other.

(3) Springs are used in the control system of moving-vane meters.

(4) These meters use air damping to brake the needle swing.

(5) They have a *square-law* scale.

(6) The meter movements respond to the average value of current, but the scale is calibrated in the rms value of the sine wave.

(7) Moving-vane meters are not usable at frequencies above 100 cps, are 5 percent accurate, and can be used as voltmeters and ammeters in circuits which will not be upset too much by their low sensitivity.

b. COPPER-OXIDE RECTIFIER METERS.

(1) Copper-oxide rectifier meters are a combination of a copper-oxide rectifier and a d'Arsonval (d-c) meter movement. The rectifier changes ac to pulsating dc, which is measured by the d-c movement.

(2) Copper-oxide rectifiers can be used in half-wave or full-wave rectifier circuits.

(3) Most practical meter circuits use a double half-wave rectifier connection. This eliminates the inefficient rectification resulting from large multiplier resistance in series with the rectifier.

(4) To obtain more linear calibration, many copper-oxide rectifier meters use shunts across the meter movement. To make the calibration more accurate, variable resistors can be placed in shunt or in series or both.

(5) These meters read low as the frequency being measured increases, because of the capacitance of the rectifier unit. The meters are usable through the audio range to about 35 kc, with the readings one-half to 1 percent low per 1,000 cps.

27. Review Questions

a. Which meters can be used for low-frequency a-c measurements?

b. Define ac, cycle, alternation, frequency.

c. Define rms, average, peak.

d. What is the form factor of a sine wave?

e. Explain the operation of a radial-vane meter.

f. Explain the operation of a concentric-vane meter.

g. What damping system is used in moving-vane meters?

h. Why do moving-vane meters have square-law scales?

i. Explain the statement, "Moving vane meters respond to the average current but are calibrated in rms values."

j. Compare the frequency response and sensitivity of moving-vane meters and copper-oxide rectifier meters.

k. Explain the construction and operation of a copper-oxide rectifier meter.

l. What is the effect on the efficiency of copper-oxide rectifiers when a large resistance is connected in series with it? Explain.

m. Draw a practical meter circuit which eliminates the difficulty indicated in question 12.

n. What purposes does a shunt serve in a copper-oxide rectifier meter?

SECTION IV
OHMMETERS

28. General

a. The ohmmeter is an instrument that indicates the resistance value of a circuit element or network on a meter scale calibrated in ohms. It is used also to locate shorted or open circuits, check circuit continuity, and provide a rough check on capacitors. The ohmmeter is one of the basic test instruments, along with the voltmeter and ammeter.

b. The ohmmeter consists of a sensitive current meter, a source of low-voltage dc, and some form of current-limiting resistor. The meter usually is a conventional d-c moving-coil type, and a battery supplies the necessary d-c voltage.

c. The values of resistance encountered in electronic equipment vary from fractions of an ohm to many millions of ohms (megohms). Most ohmmeters are constructed to cover a number of ranges from very low to very high resistance by connecting various values of current-limiting resistors in the ohmmeter circuit. The different ranges then can be selected as required by means of individual input terminals or a selector switch. When a selector switch is used, only one set of input terminals, common to all ranges, is necessary. The meter scale can be calibrated to read each individual range directly, or one meter scale can be used and a multiplying factor applied for each range.

29. Series Ohmmeter

a. In the basic ohmmeter circuit of figure 30, a 4.5-volt battery, a variable resistor, R_A, and a fixed resistor, R_B, are connected in series with a milliammeter. The two leads labeled P_1 and P_2 represent test prods which are connected across the resistance to be measured, R_x. The meter is a 0- to 1-ma movement, requiring 1 ma of current for full-scale deflection, and the internal resistance, R_M, is 50 ohms. The fixed resistor, R_B, limits the flow of current and is placed in the circuit to prevent damage to the meter. If no limiting resistor is placed in the circuit and the variable resistor is adjusted to a low value of ohms, the current flow in the circuit becomes excessive. The variable resistor, R_A, adjusts the series resistance in the circuit so that 1 ma flows when the test prods are shorted together. This occurs when the total series resistance is 4,500 ohms (4.5 volts/4,500 ohms equals 1 ma). In the circuit illustrated, the internal resistance of the meter is 50 ohms, the resistance of R_B is 4,000 ohms, and R_A is adjusted to 450 ohms, making up the required series resistance of 4,500 ohms. This gives full-scale deflection on the 0- to 1-ma meter.

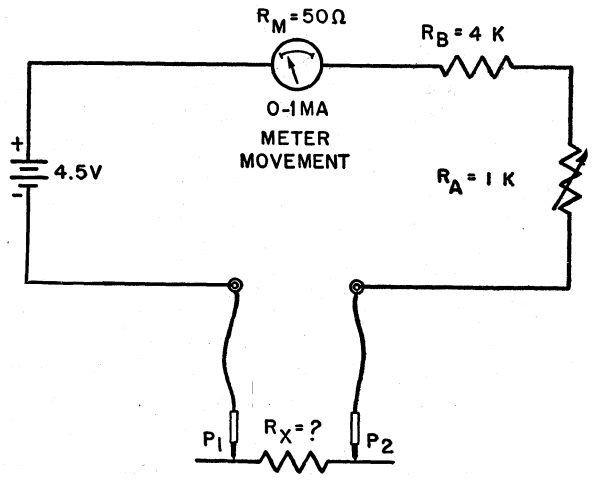


Figure 30. Basic circuit of series-type ohmmeter.

b. When the test prods are shorted, current flows through the circuit and the meter needle is deflected across the scale. A knob on the front of the panel marked OHMS ZERO ADJ (fig. 47) controls resistor R_A, and this is adjusted to provide full-scale deflection of the

meter needle. This position of the needle corresponds to 0 resistance, since the two connected prods are short-circuited across the ohmmeter terminals. In the series-type ohmmeter, full-scale deflection of the meter pointer indicates the lowest resistance; the opposite end of the scale represents the highest resistance.

c. When the battery ages, the available voltage decreases and the variable 0-ohm resistor, R_A, compensates for this condition. The current can be increased to the required value by adjusting R_A, which decreases the total series resistance. The zero-adjusting resistor, R_A, can be connected either in series or in shunt with the meter. When it is connected in shunt, a fixed resistor is connected in series with R_A, and both resistors are connected across the meter. For accuracy in meter readings, a 0-ohm adjustment is made each time the ohmmeter is used.

d. After the ohmmeter has been adjusted for full-scale deflection, the test prods are separated and the meter pointer returns to the open-circuit position on the left of the scale. Placing the prods across the unknown resistor connects it in series with the ohmmeter circuit, the current is reduced proportionately, and the meter pointer no longer deflects full scale. If the value of R_x is equal to the combined resistance of the current-limiting resistor, R_A, and the internal resistance of the meter, the total circuit resistance then becomes 4,500 plus 4,450 plus 50, or 9,000 ohms. The current in the circuit is now I equals E/R, or 4.5/9,000 equals .0005 ampere, or .5 ma. This is half of the 1 ma required for full-scale deflection, and the meter pointer is deflected only half scale.

e. When calibrating the meter scale of the ohmmeter in figure 30, the half-scale deflection point is marked 4,500 ohms. If the value of the unknown resistor, R_x, is twice the resistance of the ohmmeter, the total circuit resistance is tripled, and the current is reduced to one-third the full-scale deflection value. The meter pointer deflects to one-third full scale and corresponds to an R_x of 9,000 ohms.

f. These and other points on the ohmmeter scale can be calibrated conveniently from the formula:

$$R_x = R_c\left(\frac{I_1 - I_2}{I_2}\right)$$

where R_x = unknown resistance
R_c = total circuit resistance with prods shorted together
I_1 = ohmmeter current with prods shorted
I_2 = ohmmeter current with R_x connected across prods.

For example, find the value of R_x when the pointer deflection indicates a flow of .25 ma through the ohmmeter circuit. The value of R_x is now:

$$R_x = 4{,}500\left(\frac{1 - .25}{.25}\right) = 13{,}500 \text{ ohms.}$$

By use of this formula the entire meter scale can be calibrated to read directly in ohms the value of any unknown resistor connected across the ohmmeter test prods. The resistance values increase progressively from *right* to *left,* or from maximum to minimum deflection.

g. The series-ohmmeter circuit cannot be used to measure accurately the low resistances of coils, chokes, and transformer windings, which are often 5 ohms or less. These low values of resistance are so crowded on the right-hand side of the meter scale that distinction between them is impossible. An example of this situation can be shown by using the calibration formula given above. Assume that the ohmmeter scale has 10 divisions with the same circuit conditions as in figure 30. At nine-tenths full-scale deflection, or one division removed from the 0-ohm position, the current is .9 ma. Using the calibration formula to determine the resistance measured with this deflection,

$$R_x = R_c\left(\frac{I_1 - I_2}{I_2}\right) = 4{,}500\left(\frac{1 - .9}{.9}\right) = 500 \text{ ohms.}$$

h. If a resistance of 500 ohms causes the ohmmeter pointer to deflect over nine-tenths of the scale, any value less than 500 ohms must be read within the crowded limits of the final scale division. Consequently, since extremely low values of resistance cannot be read with the simple series-type circuit, other circuits must be used.

30. Shunt Ohmmeter

a. Low values of resistance can be measured accurately by means of a shunt ohmmeter (fig. 31). The unknown resistor, R_x, is shunted across the meter and some of the current in the

circuit takes the path through R_x. The current through the meter is reduced and the amount of deflection drops proportionately. The current flowing through the meter depends on the ratio of the shunt resistance, R_x, to the internal resistance of the meter, R_m. When the meter resistance is known, the value of R_x can be determined from the following formula:

$$R_x = R_m\left(\frac{I_1}{I_1 - I_2}\right)$$

where R_x = unknown resistance
R_m = meter resistance
I_1 = ohmmeter current —R_x not in circuit
I_2 = ohmmeter current —R_x in circuit.

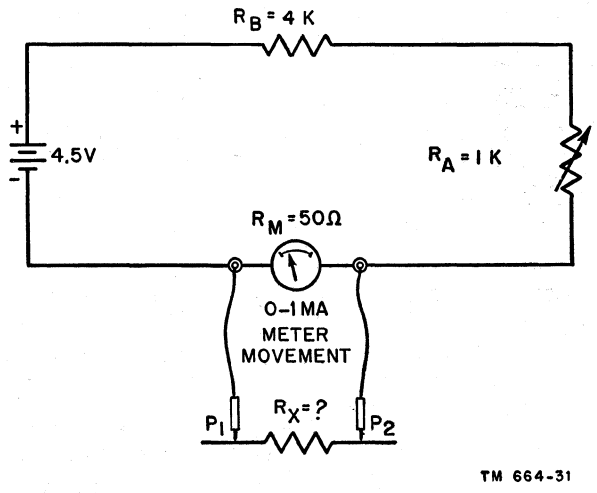


Figure 31. Basic shunt-type ohmmeter circuit.

b. With test prods P_1 and P_2 (fig. 31) open, R_A is adjusted to provide full-scale deflection on the meter, and a current of 1 ma flows through the circuit.

c. The test prods are connected across the unknown resistor, R_x, placing it in shunt with the meter. The 1-ma current in the ohmmeter circuit divides at the junction of the meter and R_x, part of it flowing through R_x and the rest flowing through the meter. The current through the meter is directly proportional to the resistance of R_x and causes a reduced deflection of the meter pointer. For example, the value of R_x is the same as the internal resistance of the meter, or 50 ohms. Because two parallel paths of equal resistance are provided, the current in the circuit divides equally, one-half flowing through the meter and one-half through R_x, so that the pointer deflects only half scale.

d. The entire meter scale can be calibrated by means of the formula given. The indicated resistance value increases progressively from *left to right,* being maximum for full-scale deflection. This is the reverse of the scale used with the series circuit of figure 30.

e. Shunting the meter resistance with resistor R_x has negligible effect on the total resistance of the ohmmeter circuit, since the combined resistance is less than 50 ohms for any value of R_x. Variations of less than 50 ohms in a series circuit having a total of 4,500 ohms represent a small fraction of the total resistance. The increase in current caused by the shunting effect of R_x is only a few microamperes. This small increase in the ohmmeter current has little effect on the ohmmeter readings and can be disregarded for all practical purposes.

f. The usable scale range of the shunt-ohmmeter circuit shown in figure 31 is approximately between 5 and 400 ohms. Resistances falling above or below these values are difficult to read with any degree of accuracy because of the crowding that occurs at the ends of the scale. Should greater accuracy be required for low values of R_x, the meter scale can be extended to provide several low-resistance ranges by incorporating meter shunts having the required resistance values. The desired range then is selected by connecting the proper shunt across the meter by means of individual terminal jacks or a multipole switch. The required shunts usually are connected across the meter by turning a rotary switch to the range indicated on the ohmmeter panel. Values as low as a fraction of an ohm can be measured with considerable accuracy, since a resistance range having very low limits can be spread over the entire meter scale.

g. A shunt ohmmeter providing three ranges for lower resistance measurement is shown in figure 32. With the selector switch in neutral position 3, the unknown resistor, R_x, is connected directly across the meter. This provides a meter range extending to about 400 ohms, as in the circuit of figure 31. When resistor R_1 is switched across the meter, part of the current is shunted around the meter and flows through R_1.

This causes a small deflection of the pointer and provides a lower resistance range, which depends on the value of shunt R_1. Resistor R_2 has a lower value than R_1, and when it is switched across the meter more of the current is shunted through it, and the meter pointer deflects less than before. The result of connecting these shunts across the meter is that progressively lower values of resistance, R_x, are required to return the meter pointer to the left end of the scale; therefore lower values of resistance are read more accurately. As each of the three ranges is used, the meter pointer must be zero-adjusted by means of resistor R_A before the unknown resistor is connected across the test prods. The prods are *not* shorted together for adjustment of this type of ohmmeter.

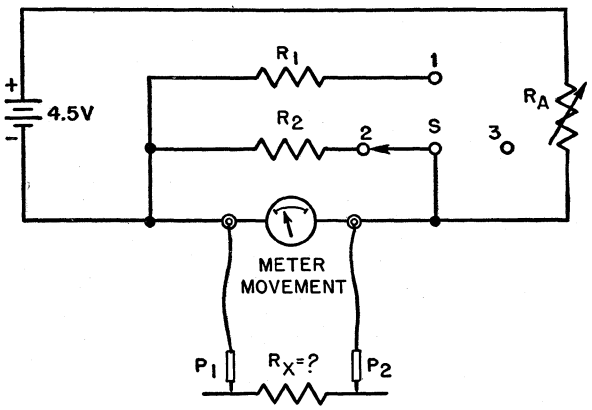


Figure 32. Shunt-ohmmeter circuit providing three low-resistance ranges.

h. With R_x connected in the circuit, the measured resistance readings increase progressively from left to right on the meter scale and maximum resistance is indicated by full-scale deflection.

31. Series Ohmmeter Using Meter Shunts

a. A circuit providing one high-resistance and two low-resistance ranges is shown in figure 33. This is a basic series ohmmeter because the unknown resistor, R_X, is placed in series with the circuit. However, shunts are placed across the meter to read ohms on the lower ranges. It is called a multirange ohmmeter since it will read more than one range.

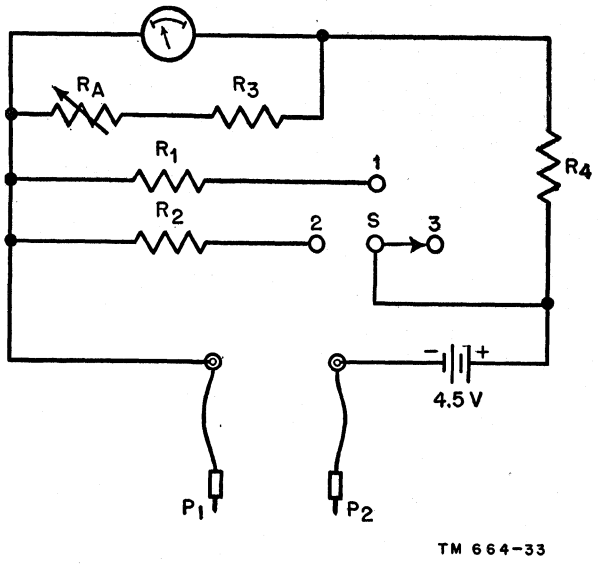


Figure 33. Series ohmmeter circuit using meter shunts.

b. To provide a better zero-adjustment, the 0-ohm adjusting resistor, R_A, and the current limiting resistor, R_3, are connected in series and shunted across the meter. This compensates for any variation in the voltage as the battery ages and permits a more accurate measurement of the unknown resistance than is obtained when R_A is in series with the meter. Resistor R_4 in series with the battery serves to limit the current in the ohmmeter circuit to the approximate value required to provide full-scale deflection on the meter, final adjustment being made by R_A.

c. With the range switch in position 3, the ohmmeter is connected as a series circuit on the high-resistance range, and high values of resistance can be measured when connected across test prods P_1 and P_2. *The test prods must be shorted together when adjusting for 0-ohm.*

d. When a lower resistance range is desired, the range switch is turned to position 1, and R_1 is then in parallel with the meter. Since this changes the series resistance of the circuit, R_A must be adjusted for 0-ohm. A lower range is available on this ohmmeter by turning the switch to position 2 and readjusting R_A.

e. Separate scales can be provided for each range to be read on a multirange ohmmeter. A more practical method, however, is to calibrate the meter in terms of the lowest scale and then to use multiplying factors to obtain the measured values for the other ranges. The multiply-

ing factors for the different ranges of the series voltmeter are usually in multiples of 10, and can be indicated on the panel as R×1, R×10, or R×100. The resistors used must be established according to the value of the multiplying factor. The indicated reading is taken directly as it appears on the scale and multiplied by the proper factor to give the true value. For example, if the reading on the scale is 30 and the range selector switch is set to a multiplying factor of 100, the true value is 30 times 100, or 3,000 ohms.

f. To measure higher values of resistance than can be accommodated on the high range of the ohmmeter circuit in figure 33, a higher value of voltage must be used. Since the current flowing in a circuit is equal to the ratio of the voltage to the resistance (I equals E/R), it is evident that, as the resistance in the circuit is increased, a point is reached where the current is insufficient to cause a deflection of the meter pointer. A higher voltage, therefore, must be used to force sufficient current through the higher resistance. The increased resistance range is directly proportional to the increase in ohmmeter voltage. For example, if the voltage of the battery in the circuit is increased 5 times to 22.5 volts, the resistance range is increased a like amount, and a multiplying factor of 5 must be applied to the existing high-resistance scale to determine the higher values of unknown resistance. An ohmmeter battery of 45 volts increases the high-resistance range 10 times, and so on. The current-limiting resistor, R_4, in the series circuit must be increased in direct proportion to the increase in voltage, becoming 5 times as great for a 22.5-volt battery and 10 times as great for a 45-volt battery. This additional resistance is required to limit the current flow to the required 1 ma for full-scale deflection.

g. The ohmmeter circuit in figure 34 uses two separate batteries, one of 4.5 volts and the other of 45 volts. A low range, two medium ranges, and a high range are available on this meter and selection of the different ranges is accomplished by a dual rotary switch, S_1 and S_2. The two lower ranges and the medium-high range are powered by the 4.5-volt battery. The high range requires the 45-volt battery, which is automatically connected into the circuit when the range selector switch is turned to the high-resistance range (position 4). The range-selector switch consists of two section, S_1 and S_2, which are ganged together mechanically and rotate in step. Resistors R_4 and R_5 are current-limiting resistors. When the 4.5-volt battery is used, resistor R_4 is connected between this battery and the meter, and R_5 is out of the circuit. When the 45-volt battery is switched into the circuit, resistor R_5 is connected in series with R_4 to limit the current flow to the value required for full-scale deflection on the meter. The higher voltage for the high-resistance range can be obtained from a built-in power supply, although this is not general practice.

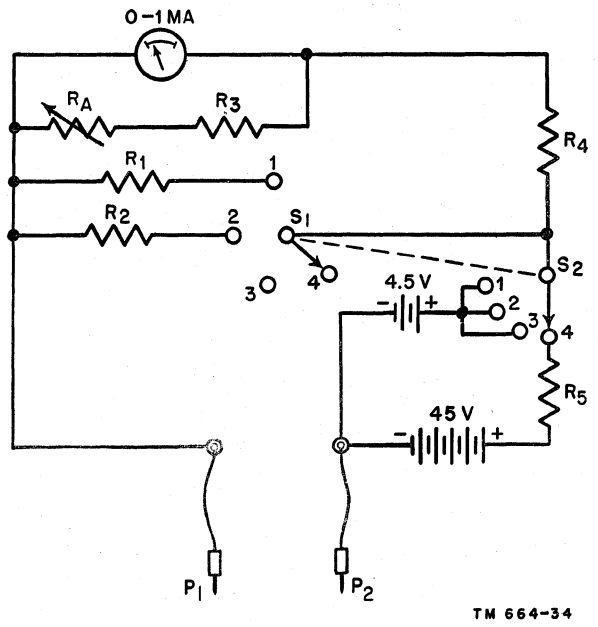


Figure 34. Multirange ohmmeter circuit. High-resistance range is powered by separate 45-volt battery.

h. The test prods must be shorted to adjust the meter to 0-ohm for each range. The shunt resistors for the low ranges are so selected that each resistance range is a multiple of 10, and the meter scale can be calibrated in terms of the lowest range. A multiplying factor then is used to obtain the measured values for each of the other ranges.

i. All the meters used in the ohmmeter circuits discussed to this point have been 0- to 1-ma, or 1,000-ohms-per-volt meters. When a meter having a greater sensitivity (that is, requiring less current for full-scale deflection) is

used, resistances over all ranges can be measured with much smaller battery voltages. A meter rated at 20,000 ohms-per-volt requires a total current of 50 μa (microamperes) through the meter for full-scale deflection. This meter is 20 times as sensitive as the meter with a 1-ma movement, and a much lower source of battery voltage is required for all ranges. The circuit of a commercial ohmmeter providing resistance measurements from .2 ohm through 20 megohms is shown in figure 35. This wide variation in resistance measurement is covered in three ranges: 0 to 2,000 ohms on the low range, 0 to 200,000 ohms on the second range, and 0 to 20 megohms on the high range. The first two ranges are powered by a 1.5-volt battery, and a voltage of 7.5 volts (1.5 plus 6) extends measurement to 20 megohms on the high range.

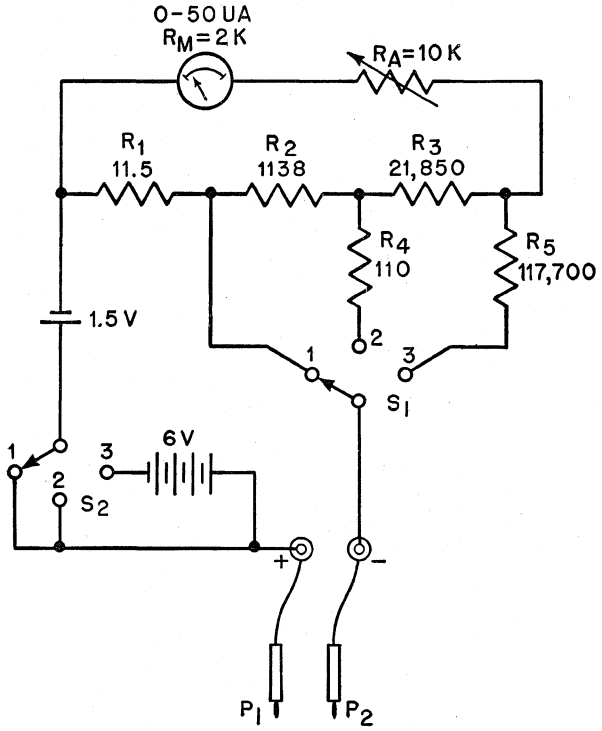


Figure 35. Commercial multirange ohmmeter circuit using highly sensitive 50-μa meter.

j. Switches S_1 and S_2 are ganged together to connect the proper shunt and series resistors in the circuit and, at the same time, to select the correct battery voltage (fig. 35). Test prods P_1 and P_2 must be shorted together and 0-ohm resistor R_A adjusted for full-scale deflection on the meter before each range is used. The meter scale is calibrated in terms of the lowest range and a multiplying factor (indicated on the panel) is used to determine resistance values on the other two ranges. The meter is read from right to left, the highest resistance for each range being at the extreme left of the scale. Five 1.5-volt dry cells are used to supply battery power for the ohmmeter circuit. Shunt resistors are placed across the meter for all ranges to restrict the current flow through the meter to the maximum required for full-scale deflection.

32. Using Ohmmeter

a. Care must be taken to avoid connecting the ohmmeter across circuits in which a voltage exists, since such a connection can result in damage to the meter. Although the power switch normally performs the function of removing applied voltage from the equipment, the switch itself can be defective. Therefore, *to insure the removal of all voltage to the equipment under test, disconnect the source of input voltage by removing the power plug.* Batteries or bias cells to provide fixed bias or other operating voltages may be included in the circuits under test and the ohmmeter must not be connected across these sources of voltage. All capacitors must be discharged before the ohmmeter prods are connected in the circuit, since charges remaining on capacitors after the applied voltage has been removed can damage the meter severely. Because the resistance of circuit elements in a heated condition may differ considerably from that in a cool state it is advisable to wait a few minutes after the power has been removed before applying the ohmmeter to the equipment.

b. When resistance measurements are made in a circuit, each element can be tested individually by removing it from the circuit and connecting the ohmmeter test prods across it. However, this method consumes time, and usually measurements are made from various points in the circuit to a selected common reference point (chassis or B-minus). In this manner, complete sections of the circuit can be measured quickly to determine the presence of abnormal conditions. Charts indicating *point-to-point resistance* values usually are supplied with the equipment. The ohmmeter is connected across the

designated points, and the readings obtained are compared with those on the chart. When an abnormal resistance reading is obtained, each element in the circuit is isolated and tests are made to determine the cause of the abnormality.

c. To avoid erroneous readings when no resistance chart is available, care must be taken to ascertain that other circuit elements are not connected in parallel with the element being measured. The element under test usually can be isolated by opening one of its connections in the circuit.

d. A leaky capacitor connected in parallel with a resistor under test can pass current and will indicate a resistance reading depending on the degree of leakage. The reading obtained on the ohmmeter is the resultant of the circuit resistance and the parallel leakage resistance of the capacitor. With a leaky capacitor in the circuit, a reading is obtained even if the shunt resistor is completely open, and it is necessary to disconnect one end of the circuit element before taking a measurement.

e. The hands of the technician should not come in contact with the metal tips of the test prods, since the resistance of the human body under certain conditions is low, less than 50,000 ohms, and may cause erroneous readings. This is particularly noticeable when a high resistance is being measured. *All resistance measurements should be made with the hands holding the insulated portions of the test prods.*

f. The ohmmeter can check roughly the condition of capacitors and determine the presence of short circuits or leakage. When testing capacitors, other than electrolytics, the ohmmeter selector switch is turned to the highest range, since this provides the highest source of voltage available in the ohmmeter. The meter is observed closely and the test prods are connected to the capacitor. With a good capacitor, the meter pointer deflects slightly and returns quickly to the infinite-ohms position as the capacitor charges across the ohmmeter battery. Small values of capacitors cause a slight deflection of the meter pointer and return quickly to the infinite position; larger values cause a greater deflection and a longer time is taken for the pointer to return. However, if the capacitor is good, the meter pointer will return to the infinite-ohms position in a relatively short time. If no deflection is obtained an open capacitor is indicated, or the capacitance of the unit is too small to cause a deflection. A full-scale deflection of the pointer indicates a shorted capacitor, and leakage is indicated by a steady deflection on some part of the scale. The resistance of a paper capacitor should be over 50 megohms per microfarad, and that of a mica capacitor should be over 100 megohms per microfarad.

g. When testing electrolytic capacitors, the ohmmeter is set to the high range and the prods are connected across the capacitor. Because current passes more readily through the electrolytic capacitor in one direction than in the other care must be taken to observe polarity or the reading obtained will be incorrect. When the prods are connected to the capacitor, a large deflection occurs on the meter and the pointer returns slowly toward the infinite-ohms position as the capacitor takes a charge. Usually, some reading is obtained even when an electrolytic capacitor is fully charged. For a good capacitor rated at 450 working volts dc, the final ohmmeter reading should be over 500,000 ohms. Low-voltage electrolytic capacitors should read at least 100,000 ohms to be acceptable.

33. Summary

a. An ohmmeter is an instrument for measuring resistance.

b. The basic series ohmmeter consists of a meter, a variable resistor, a limiting resistor, and a battery connected in series with the resistor to be measured. The deflection of the meter pointer caused by the current through the series circuit indicates the resistance value on the meter scale, which is calibrated in ohms.

c. Several resistance ranges are required to provide accurate measurement of resistances ranging from very low to very high values.

d. A shunt ohmmeter circuit provides a convenient means of measuring low resistances. In this circuit, the unknown resistor is connected in parallel with the meter movement.

e. Ohmmeters covering a number of resistance ranges are known as multirange ohmmeters.

f. The meter scale on multirange ohmmeters usually is calibrated for the lowest resistance

range. Multiplying factors then are used to interpret meter readings for the higher ranges. Individual ranges generally are selected by means of a range selector switch.

g. In some multirange ohmmeters, the highest range on the meter is powered by a separate voltage source, usually a battery providing higher voltage.

h. Care must be taken when using the ohmmeter to prevent connection of the meter across circuits containing voltage, or the meter can be damaged.

i. In addition to measuring resistance and checking continuity in circuits, the ohmmeter can provide a rough check on the condition of capacitors.

34. Review Questions

a. What is an ohmmeter?

b. What is a series ohmmeter? A shunt ohmmeter?

c. Why are different resistance ranges required in an ohmmeter?

d. How can the low-resistance range on the ohmmeter be extended?

e. How can the high-resistance range on the ohmmeter be extended?

f. When the ohmmeter is calibrated with a single scale, what range does this usually represent?

g. How are the readings obtained on a single scale interpreted to indicate the measurements made on the various ranges?

h. Why must each range be adjusted for 0-ohm before the ohmmeter is used?

i. When resistance measurements are made in electrical circuits, what is the primary precaution to be observed?

j. Should resistance measurements be made across a resistor and a capacitor in parallel? Why?

k. Why must the test prods always be held by the insulated parts?

l. In checking electrolytic capacitors with the ohmmeter, why must polarity be observed?

SECTION V

VACUUM-TUBE VOLTMETERS

35. Principles of Vacuum-Tube Voltmeter

a. DESCRIPTION AND USE.

(1) A vacuum-tube voltmeter is an instrument for measuring a-c or d-c voltages and using one or more vacuum tubes in a special circuit containing a meter. The operating power for the tubes usually is obtained from a built-in power supply working off an a-c line, but batteries can be used. Different types of probes are used with the instrument for measuring d-c voltages to very high values and a-c voltages over a wide band of frequencies. The vtvm also is known as an *electronic voltmeter.*

(2) The primary advantage of the vtvm over ordinary meters is its ability to measure voltages without loading the circuit. Normal operating conditions are left more or less undisturbed since the vtvm draws negligible current from the circuit under test. This is of special advantage in low-power circuits where the conventional voltmeter changes the circuit conditions and produces false readings.

(3) The vtvm can be used to measure a-c voltages over a frequency range extending from 5 or 10 cycles to several hundred megacycles. Specially designed instruments have an upper frequency limit of several thousand megacycles and can be used for testing high-frequency equipment.

(4) The vtvm can be used to measure low voltages in high-impedance circuits, since the input impedance of the vtvm usually is standardized at approximately 10 megohms. The loading effect is negligible when this impedance is placed in shunt with the circuit under test, and the measurement of low voltages can be accomplished with a high degree of accuracy. The conventional meter, having much lower input impedance on the low-voltage ranges, loads the circuit and produces erroneous readings.

b. BASIC D-C VACUUM-TUBE VOLTMETER.

(1) The simplest type of vtvm consists of a diode tube, a d-c milliammeter, and a load resistor connected in series with the d-c voltage to be measured (fig. 36). When an unknown voltage, E_x, of the proper polarity is applied to the input terminals, the plate of the diode becomes positive with relation to the cathode, and current flows through the circuit. This current flow, being directly proportional to the applied voltage, deflects the meter pointer accordingly. Since the input impedance of a series-diode circuit is relatively low, a load resistor is used to increase it; this minimizes loading effects of the circuit under test. However, if the load resistor is made large enough to satisfy impedance requirements, a sensitive microammeter must be used to obtain satisfactory deflection with the limited current flow. The value of load resistance chosen, therefore, must be a compromise. This problem is overcome in a vtvm using a triode tube.

(2) The basic d-c vtvm circuit in A of figure 37 consists of a triode, a source of plate voltage, a source of grid bias, and a d-c milliammeter calibrated to read

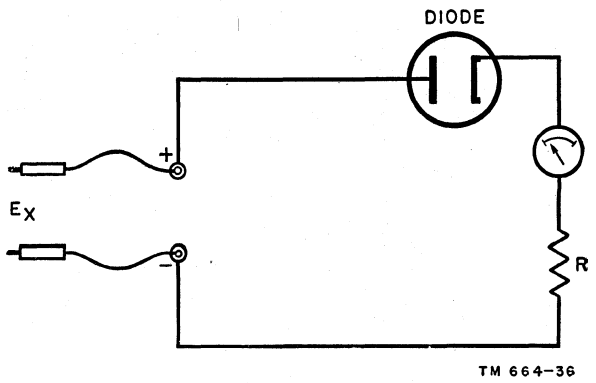
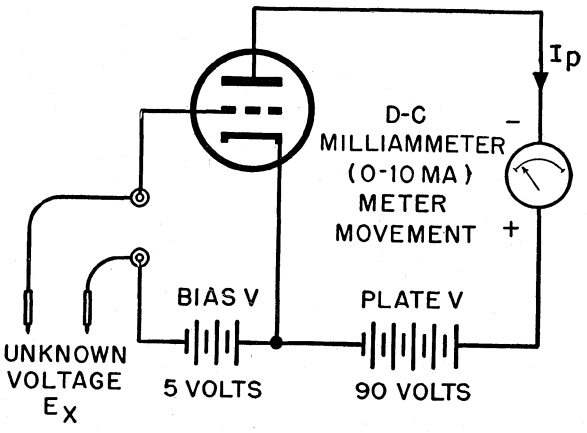


Figure 36. Basic d-c vacuum-tube voltmeter using a diode.

the voltage applied between the grid and cathode of the tube. The negative 5-volt bias on the tube grid establishes the operating point at cut-off, as shown in the grid-voltage plate-current characteristic curve in B. No current flows through the tube with 0 input voltage, and the meter in the plate circuit reads 0. When a voltage is applied to the input terminals, plate current flows through the circuit, actuating the meter pointer.

(3) Since the applied voltage, E_x, causes the tube to operate along the straight portion of the characteristic curve, the increase in plate current is directly proportional. For example, if a voltage, E_x, equal to +2 volts is applied to the voltmeter, the bias on the grid of the tube is reduced to —3 volts, 4 ma of current flows in the plate circuit, and the meter pointer is deflected this amount. This is shown in B by the horizontal and vertical dashed lines which intercept the tube characteristic curve at the indicated points. When E_x is equal to +4 volts, I_p is equal to 8 ma; intermediate values of voltage can be determined by means of the characteristic curve for values of E_x from 0 to +5 volts. The meter scale then can be calibrated directly in terms of voltage.

(4) This simplified triode circuit arrangement is limited in application, since it can be used only for the measurement of d-c voltages having a maximum value of 5 volts. Commercial vacuum-tube voltmeters are designed



SIMPLE D-C
VACUUM-TUBE VOLTMETER

A

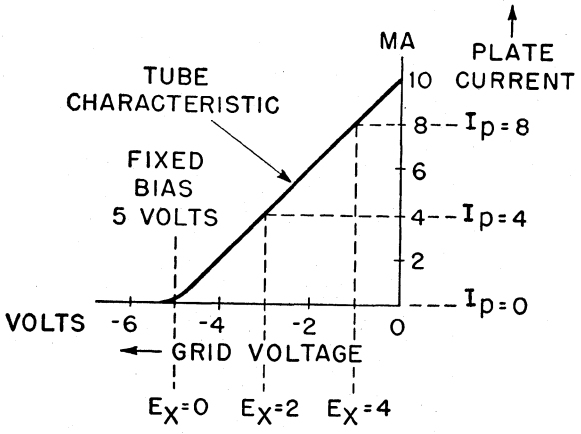


PLATE-CURRENT
GRID-VOLTAGE CURVE

B

TM 664-37

Figure 37. Basic d-c vacuum-tube voltmeter using a triode.

to permit measurement of both a-c and d-c voltages on a number of different ranges from millivolts to many thousands of volts.

c. BASIC A-C VACUUM-TUBE VOLTMETER.

(1) A simple circuit for the measurement of a-c voltages is shown in A of figure 38. Although this circuit is the same as that used for the measurement of d-c voltages it can be used to measure a-c voltages from 0 volts to 5 volts over a wide frequency range.

(3) Conduction of current on the positive alternations of the applied a-c voltage produces current pulses having the waveform shown in B. The meter pointer is unable to follow these current pulses to indicate *peak* values, but responds to the *average* value of the current flowing in the circuit. An examination of the plate-current waveform shows the average value of the pulse at maximum plate current to be 3.2 ma. By selecting a meter which

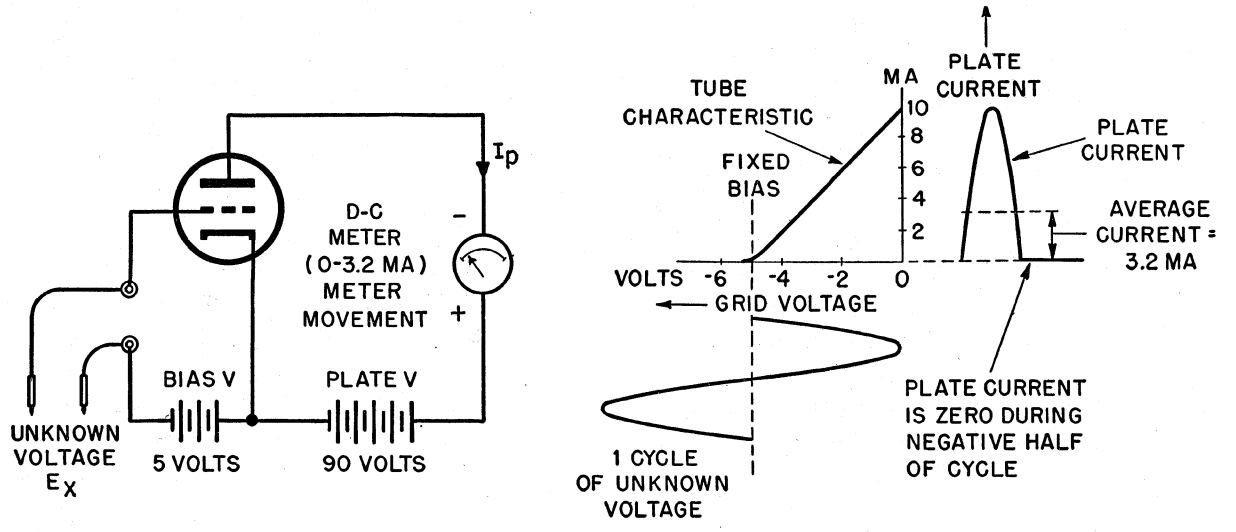


Figure 38. Basic a-c vacuum-tube voltmeter.

(2) When no voltage, E_x, is applied to the input terminals, the tube is at cut-off because of the negative 5-volt bias on the grid of the tube, and the meter reading is 0. This point is marked on the grid-voltage plate-current curve in B. When an a-c voltage is applied at the input terminals, the positive alternation reduces the negative grid bias in direct proportion to the value of the positive half-cycle and the tube draws current. Since the tube is biased to cut-off, the negative alternation has no effect on circuit conditions.

requires 3.2 ma for full-scale deflection, maximum deflection is obtained when the peak positive alternation of the input voltage is equal to 5 volts, and grid bias is reduced to 0. The meter then can be calibrated in terms of *peak* a-c voltage, since the current through the meter is determined by the applied input voltage. A-c vacuum-tube voltmeters can be calibrated to read average, peak, or rms values.

d. PROBES.

(1) A probe is a test prod designed for a specific meter application and con-

nected by means of a cable to the input terminals of the meter. Some probes increase or decrease the input resistance or capacitance of the voltmeter; some act to isolate the dc and to minimize the loading effect of the d-c voltmeter on circuits carrying a-f and r-f signal voltages; some use extremely high resistance to act as multipliers. Where the unknown voltage must be rectified before it is applied to the voltmeter, the rectifier unit usually is mounted inside the probe.

(2) The simplest probe used with vtvm's in measuring d-c voltages is one having a series resistor mounted inside. The value of this resistor may be between 1 and 5 megohms, but 1 megohm is the value most commonly used. The purpose of this resistor is to prevent the loading or detuning of a circuit when using the probe to make d-c voltage measurements.

(3) One probe used to measure a-c voltages has a small capacitor of approximately .5 $\mu\mu$f (micromicrofarads) that is connected in series with the input. The capacitor reduces the input capacitance of the voltmeter to a low value and reduces detuning effects when making a-c measurements in tuned circuits. The capacitor also blocks any d-c voltages from appearing in the voltmeter, and prevents the measured a-c voltage from being affected by the presence of a d-c voltage.

(4) The germanium-crystal probe has an extended high-frequency response and a low input capacitance, and is used widely for the measurement of high-frequency a-c voltages. It has the disadvantage of not being able to withstand high voltages.

36. Types of Vacuum-Tube Voltmeters

a. RECTIFIER-AMPLIFIER VTVM.

(1) A block diagram of a vtvm used in servicing communication equipment is shown in figure 39; the basic circuit is shown in figure 40. A-c and d-c voltages over several higher ranges can be measured by means of external multipliers. The amplifier section of the voltmeter contains two triode tubes, V2 and V3, in a balanced circuit. The d-c meter has a current sensitivity of 200 μa and is connected in the amplifier section. For the measurement of a-c voltages a probe with a rectifier tube incorporated is connected to the input terminals of the

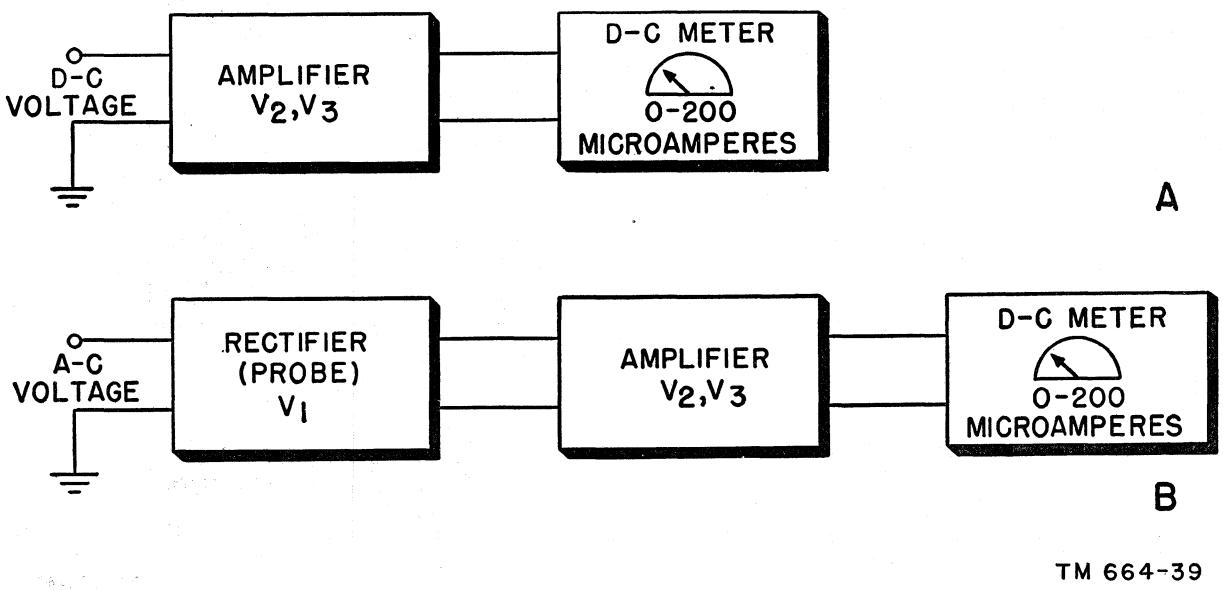


Figure 39. Block diagram of rectifier-amplifier vacuum-tube voltmeter.

amplifier through a short length of shielded cable. Operating voltages for the tubes are obtained from a built-in power supply (not shown), and each separate a-c or d-c range is selected by means of push buttons on the panel.

(2) The basic circuit (fig. 40) of the amplifier section is a balanced d-c amplifier. The meter switching arrangement permits circuit A to measure negative d-c voltages and circuit B to measure positive voltages. The 300-volt power-supply voltage is divided so that a positive 150 volts is applied to the two triode plates through potentiometer R_5, and a negative voltage is applied to the cathodes of the two tubes. Potentiometer R_5 is the 0-ohm adjustment on the panel, and permits adjustment of the plate voltage to compensate for differences in the characteristics of the two tubes. The d-c microammeter is in series with range-calibrating resistors R_A and R_B and is connected between the two cathodes.

(3) With equal voltages on the plates of the tubes and no voltage applied to the voltmeter input terminals, the current through each tube is of equal value. Since equal currents flow through both cathode resistors, the voltage drop across each one is the same, the potential between cathodes is the same, and the meter indicates 0. When an unknown voltage is applied to the grid of either tube in figure 40, one tube draws more current than the other, the circuit is unbalanced, and current flows through the meter. By properly calibrating the meter scale, the amount of plate-current deflection is made directly proportional to the value of the applied voltage.

(4) When a negative 10 volts dc is applied to the grid of V_2 in circuit A, the voltage across R_{25} causes the cathode of V_2 to become less positive, and the cathode of V_3 becomes more positive. A current flows from the cathode of V_2 through the meter and calibrating resistors R_A and R_B to the cathode of

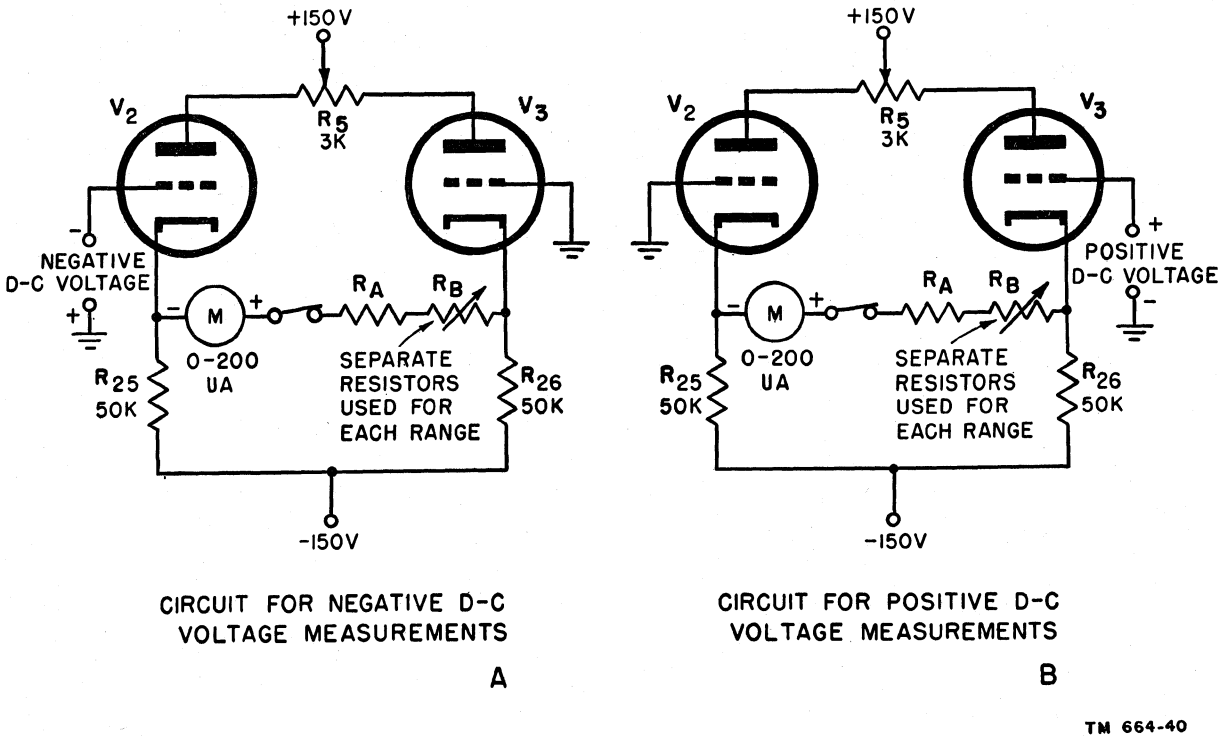


Figure 40. Simplified schematic diagram of balanced d-c amplifier.

V_3, and the meter pointer deflects over the scale. Since the deflection is proportionate to the value of the unknown voltage applied to the tube, the point of deflection can be calibrated as 10 volts on the meter scale.

(5) If the unknown voltage is positive in polarity, it is applied to V_3, in circuit B. A positive voltage on the grid of V_3 makes the cathode of V_3 more positive than the cathode of V_2, and current flows through the meter from V_2 to V_3. The current flows the same way through the meter for the measurement of either positive or negative voltage. A two-circuit switch is incorporated in the meter circuit to switch the input terminals from one tube to the other when measuring positive or negative voltages. When voltage of either polarity is applied to one tube, the grid of the other tube is grounded to satisfy the operating conditions.

(6) Separate sets of calibrating resistors are switched in series with the meter for each voltage range. One of these resistors, R_A, always is fixed, and the other resistor, R_B, is variable to enable the voltmeter to be calibrated accurately. These calibrating resistors act as multipliers, and when the voltage to be measured is increased in value, the resistors also must be increased so that the current flow through the meter is limited to the maximum rated 200 μa required for full-scale deflection. The circuit is fairly stable for the higher voltage ranges but, on ranges of 3 volts or less, resistor R_B in series with the meter is low in value and the stability of the circuit is not as good.

(7) A probe containing a dual diode, which rectifies the a-c voltage before it is applied to the amplifier circuit, is used when a-c voltages are being measured (fig. 41). Although the diode tube is shown adjacent to the schematic of the amplifier circuit, it is located in the probe and connected to the voltmeter circuit by a cable. The voltage to be measured is applied to one-half, V_1-A, of the dual diode; the other half, V_1-B, is connected to the grid of V_3.

(8) With no voltage applied to rectifier diode V_1-A, the plate of the diode is approximately 1 volt negative in relation to ground. This voltage, called contact potential, is the result of electrons leaving the heated cathode with

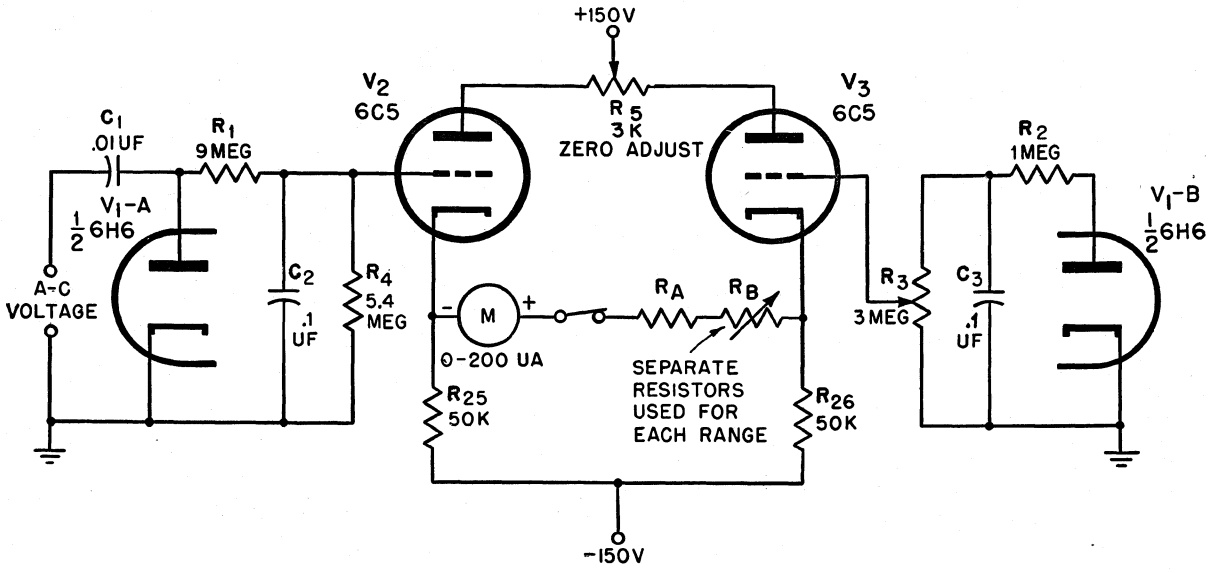


Figure 41. A circuit for measuring a-c voltages.

sufficient velocity to reach the plate of the tube. This flow of electrons causes a voltage drop across the plate load of about 1 volt and appears at the grid of tube V_2, unbalancing the amplifier. To compensate for this, and restore the amplifier circuit to perfect balance, an equivalent potential is applied to the grid of tube V_3 by connecting diode section V_1-B to the grid of V_3. The correct value of contact potential to counteract the effect of the voltage on the grid of V_2 is obtained by adjusting potentiometer R_3 until the amplifier circuit is balanced properly. This condition exists when the meter reads 0 with 0 voltage applied to the voltmeter.

(9) Diode V_1-A functions as a half-wave rectifier, and the rectified current flowing through R_1 and R_4 drives the grid of V_2 negative. This negative voltage unbalances the circuit and causes a current to flow through the meter that is proportionate to the applied voltage. Capacitor C_2 filters the rectified voltage and C_1 serves to block any d-c voltage present in the circuit being measured.

(10) Different sets of calibrating resistors are required for each of the a-c voltage ranges. The meter scale for ranges of 3 volts or less is nonlinear because the diode does not provide linear rectification at low voltages.

(11) Placing the rectifier in the probe permits the use of the basic d-c amplifier circuit for all a-c measurements. When the applied a-c voltages are rectified in the probe, a wider frequency range is available, since cable capacitance and inductance have no effect on d-c voltages.

b. AMPLIFIER-RECTIFIER VTVM.

(1) Although the rectifier-amplifier type of vtvm can measure voltages over a wide range of frequencies, it is limited in sensitivity since low values of signal voltages, in the order of millivolts, cannot be measured. By connecting one or more resistance-coupled amplifier stages ahead of the rectifier, voltages in the order of microvolts can be amplified sufficiently to be read on the meter. Because of frequency discrimination in the amplifier stages, the amplifier-rectifier vtvm is not readily applicable to the measurement of very high r-f voltages. It is widely used, however, in the measurement of audio and radio frequencies up to several megacycles. Depending on the particular circuit arrangement and application, it is called the audio-frequency, logarithmic, or wide-band vtvm.

(2) The circuit in figure 42 provides multirange operation from 1 millivolt to 100 volts and uses two stages of amplification before rectification. The high range can be extended by means of multipliers to accommodate several thousand volts. The frequency range extends from 10 cps (cycles per second) to 150 kc (kilocycles). For simplicity, triode tubes are shown in the amplifier stages, but pentodes are used in the actual instrument. Following amplification, the input voltage is rectified by means of a dry-disk rectifier, and the meter is actuated by the rectified current flowing through it. A portion of the output voltage is fed back to resistor R_1 in the cathode of V_1 to stabilize the instrument.

(3) In operation, the unknown a-c voltage is applied to the grid of V_1 through the range-selector network, and amplified. From there the voltage is coupled to the second stage, where it undergoes further amplification. The amplified voltage then is fed through coupling capacitor C to the final circuit consisting of the rectifier in series with the meter. Resistor R_2 limits the current through the meter. When the voltage at C is positive, current flows through the rectifier circuit. Simultaneously, the voltage developed across R_1 increases the negative bias on V_1 and reduces the over-all gain of

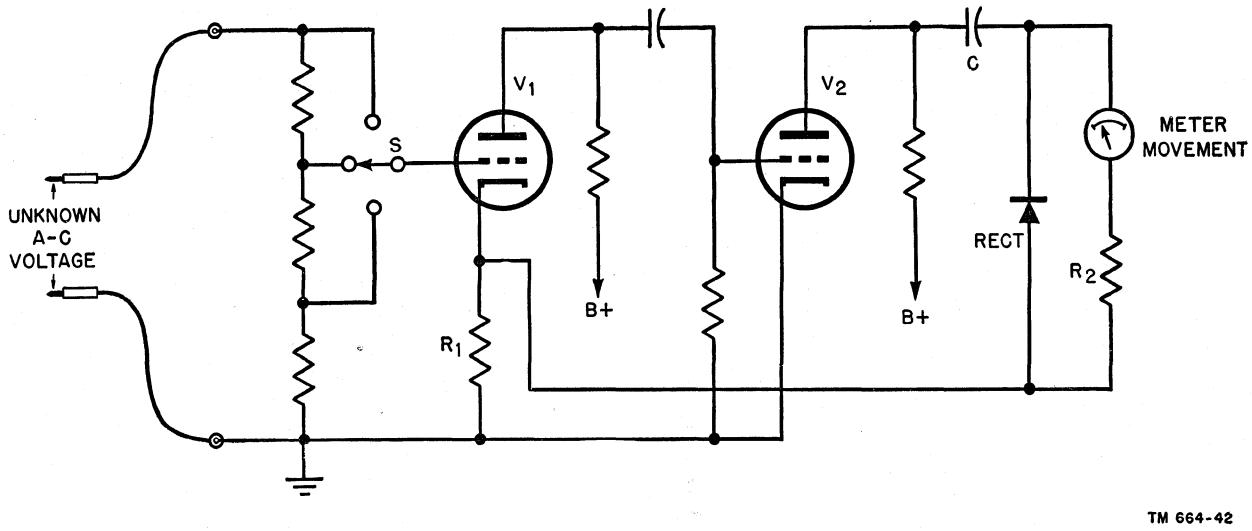


Figure 42. A two-stage amplifier-rectifier vacuum-tube voltmeter using negative feedback.

the amplifier stages, with attendant increase in stability.

c. SLIDE-BACK VTVM.

(1) The basic circuit of a slide-back vtvm used in specialized applications is shown in figure 43. This voltmeter is not a direct-reading type such as those previously described.

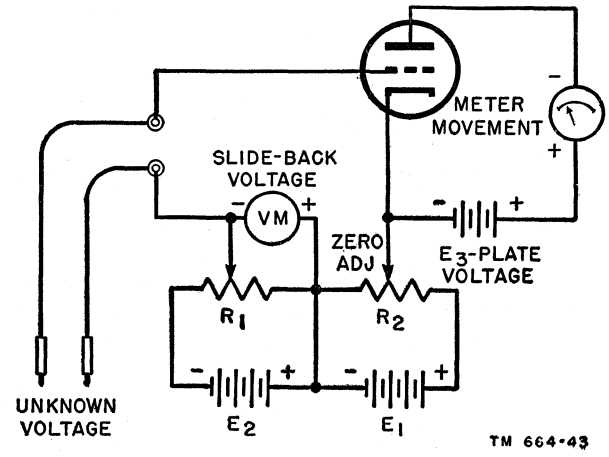


Figure 43. Basic circuit of slide-back vacuum-tube voltmeter using triode.

(2) Potentiometer R_1, which determines the slide-back voltage, is adjusted to produce a 0 reading on the voltmeter. The input terminals then are shorted together, and potentiometer R_2, labeled ZERO ADJ, is adjusted to provide a small reading ($\frac{1}{10}$ or $\frac{1}{20}$ of full scale) on the microammeter in the plate circuit of the tube. Potentiometer R_1 then is readjusted to place a high negative voltage on the grid of the tube. This prevents overloading when the input voltage is too high. The unknown voltage then is connected to the input terminals of the meter.

(3) The effect of the applied input voltage is to cancel some or all of the bias voltage on the grid, and to increase the current flow through the tube. To find the value of the input voltage, the slide-back voltage potentiometer, R_1, is adjusted until the plate current is reduced to the initial value ($\frac{1}{10}$ or $\frac{1}{20}$ of full scale) when no d-c voltage was applied to the input. The reading on the voltmeter then is the value of the applied voltage. The value of the unknown voltage is indicated on the voltmeter when the slide-back voltage and the unknown voltage are equal. With the voltages equal in value, reading the value of the slide-back voltage indicates the value of the unknown voltage.

(4) In some slide-back voltmeters, a single meter is used to indicate the current null point when the slide-back voltage

is adjusted. The unknown voltage is obtained by setting the slide-back potentiometer along a scale calibrated for this purpose.

d. TUNED VTVM. Although vacuum-tube voltmeters usually respond with equal accuracy to a-c voltages over a wide range of frequencies, certain applications require a voltmeter which is frequency selective. To obtain greater sensitivity, one or more tuned stages of amplification can be connected ahead of the meter circuit. The tuned circuit is made variable over a band of frequencies, and any frequency within these limits can be selected and measured. The tuned vtvm finds application in signal tracers, harmonic analyzers, and similar instruments.

37. Using VTVM

a. PRECAUTIONS.

(1) The vtvm is a sensitive measuring device, and subjecting it to a voltage above its rated limit may damage the instrument. *Always connect the voltmeter across a circuit with the range switch initially set on the highest range.* If this does not give a sufficient needle deflection, decrease the range by steps until a convenient reading is obtained.

(2) When using probes for high-voltage checking, always grip the probe near the rear of the handle. This reduces the electric-shock hazard and also decreases the capacitive effects of the hands on the circuit. *If possible, connect the probe to the high-voltage circuit under test before turning on the voltage in the circuit.* High d-c voltages, when present in a-c circuits under test, charge the input coupling capacitor of the meter. If the a-c probe and a ground point are touched at the same time, a dangerous shock may result. To prevent this, *ground the a-c probe immediately after testing such circuits.*

(3) Other precautions to follow for high-voltage measurement are:

(*a*) Locate all high-voltage points in the circuit under test *before* making measurements.

(*b*) Always work with one hand in your pocket.

(*c*) Make sure that no part of your body touches ground at any time.

(*d*) Any point in a piece of defective equipment may contain high voltages. Use the probe when in doubt.

(*e*) When measuring current in high-voltage circuits, always break the circuit at or near ground potential.

(4) In high-frequency measurements using an r-f probe, the ground point for the probe should be as close to the measurement point as possible. *Lead wires, no matter how short, cause substantial voltage drops at high frequencies.* For this reason, it is very important to connect the high side of the voltmeter to the exact point where a reading must be taken.

(5) The a-c ranges of vtvm's are calibrated to read the rms (root mean square) value of a sine-wave voltage. Therefore, when voltages other than sine wave are measured, true readings cannot be taken unless the vtvm measures peak-to-peak voltages. The vtvm is not recommended for measurement of nonsinusoidal voltages except where accuracy is not required and only comparison measurements are desired. The calibration of the vtvm should be checked at frequent intervals.

b. APPLICATIONS.

(1) To operate the vtvm, turn on the power switch and allow the meter to warm up for several minutes. Set the meter needle at 0 by using the zero-adjustment knob on the front panel. If the needle does not drift from the 0 setting, measurements may be made. The exact operating procedure for the various ranges of the instrument vary with the different types and are described in the instruction manual for each meter.

(2) Because of its high input impedance, the vtvm is useful for making voltage

measurements in relatively high-impedance circuits. For example, a vtvm with an input impedance of 10 megohms is used to measure the voltage drop across a 2-megohm grid-leak resistor. The total resistance of the resistor and the meter in parallel is 1.7 megohms. This is so close to the value of the resistor that the current drawn will be practically the same with or without the voltmeter in the circuit. Therefore, voltage measurements can be made without disturbing circuit operation. Similarly, voltage measurements can be made in tuned circuits where the impedance of the various elements is critical and a slight change of the impedance of the circuit (as results when using low- or moderate-impedance measuring instruments) can disturb circuit operation.

(3) Because of its wide frequency range, the vtvm is particularly suitable for measurement of gain in an amplifier stage. This is accomplished by measuring the voltage output of the amplifier for various frequencies and dividing this reading by the voltage input. Such measurements can be made on a single stage (fig. 44), or on a group of stages taken together. The voltage input to the stage or stages is furnished by a signal generator, a device which furnishes a continuous-wave signal with constant peak amplitude at various frequencies.

(4) Vtvm's can be used to locate defects in radio receivers and transmitters by applying a source of signal voltage to the input of the receiver or transmitter, and measuring the voltage developed at every critical point. The amplifier-rectifier vtvm is used for this method of signal tracing because the voltages at some points in the circuit are small and must be amplified before they are measured. Tuned amplifier-rectifier vtvm's are used in commercial signal-tracing instruments for measurement of distortion, hum, and amplifier gain. These measurements help to determine the stage in which defects exist, and the process is called defect localization. Other measurements possible with the vtvm include the checking of avc (automatic-volume-control) voltage, discriminator voltage (in f-m receivers and radar sets), and the grid-bias voltage of oscillators.

38. Summary

a. A vtvm is a voltage-measuring instrument using vacuum tubes and a meter.

b. The advantages of the vtvm over ordinary meters are—higher input impedance, higher sensitivity, greater overload protection, and wider frequency range for a-c measurements.

c. A simple type of d-c vtvm uses a triode with the grid biased initially at cut-off and a meter placed in the plate circuit. When a pos-

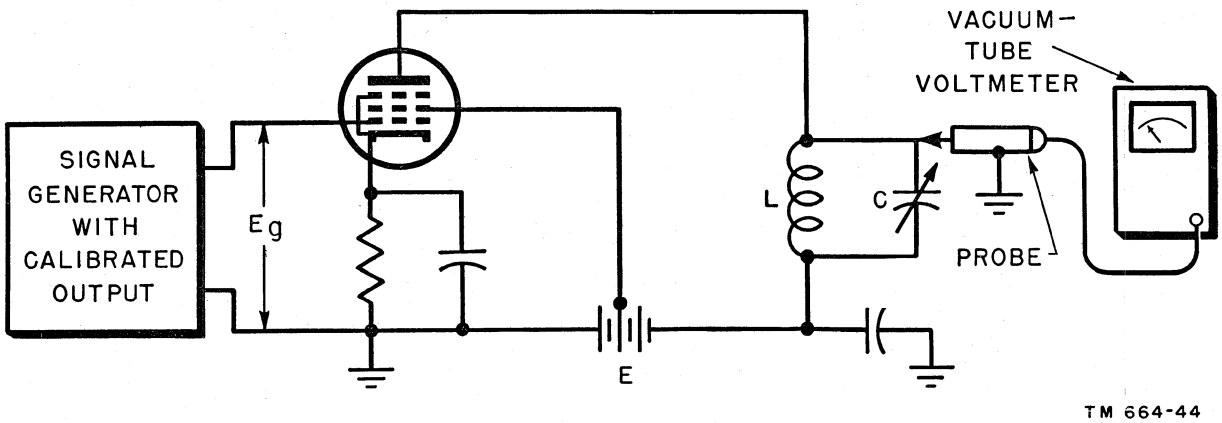


Figure 44. Measuring gain of an r-f amplifier stage with vacuum-tube voltmeter.

itive unknown voltage is fed to the grid, the negative bias voltage is reduced, and plate current flows through the meter in proportion to the input voltage.

d. The same circuit can be used to measure a-c voltages. Plate current flows only during the positive alternation of the unknown voltage, and the meter responds to the *average* value of the input voltage. The meter scale can be calibrated to read average, rms, or peak values.

e. A probe is a device used with a meter for measuring various points within an electrical circuit. It contains a circuit designed either to isolate the vtvm from the circuit under test, or to rectify an unknown a-c voltage to be measured by the meter.

f. The most popular vtvm's are the rectifier-amplifier, the amplifier-rectifier, the slide-back, and the tuned types.

g. The rectifier-amplifier type consists of a rectifier stage (which can be incorporated in the probe), followed by one or more d-c amplifier stages, and a d-c meter connected in the amplifier section.

h. Generally, balanced d-c amplifiers are used in vtvm's. The application of an unknown voltage to the meter results in a condition of unbalance in the amplifier, causing a current to flow through the meter in direct proportion to the value of the unknown voltage.

i. With no external voltage applied to a diode, there is a small current through the diode because the plate traps a small number of the electrons constantly emitted by the heated cathode. The voltage drop resulting at the plate is called the contact potential. To balance this contact potential, a dual-diode is used. The contact potential of one diode is used to nullify the contact potential of the other.

j. By rectifying the a-c voltage and applying it to a d-c amplifier, the rectifier-amplifier vtvm is able to measure a-c voltages over a wide frequency range.

k. Amplifier-rectifier vtvm's are useful for low-voltage a-c measurements where the unknown voltage first must be amplified to give an appreciable reading.

l. Slide-back vtvm's work on the potentiometer principle; that is, the unknown voltage is balanced by adjusting an internal source of voltage in the meter. This is useful for *peak* a-c measurements.

m. In tuned vtvm's, a tuned circuit is incorporated in the instrument ahead of the meter to select a desired frequency. Only voltages of this frequency are measured.

n. The vtvm is a sensitive instrument that can be damaged if mishandled. Proper precautions for its use are included in the instruction book furnished with it, and should be observed.

o. Vtvm's are particularly applicable for voltage measurements in high-impedance circuits, for amplifier-gain measurements, and for signal tracing.

39. Review Questions

a. What are the advantages of the vtvm as compared with ordinary voltmeters?

b. Why is the current through the meter in a simple triode, d-c vtvm proportional to the unknown voltage fed to the grid?

c. Explain the operation of the simple a-c triode vtvm.

d. Name four types of probes. What is each type used for?

e. Why are balanced d-c amplifiers used in vtvm's? How do they work?

f. Why is the rectifier-amplifier vtvm capable of measurements over a wide frequency range?

g. How is a vtvm made to have different voltage ranges? Why is the low-voltage range of the vtvm sometimes inaccurate?

h. When is the amplifier-rectifier type used? Slide-back type? Tuned?

i. Explain the operation of the slide-back type.

j. Give five precautions that should be observed when using the vtvm for high-voltage measurements.

k. Why do most vtvm's give misleading readings when used to measure nonsinusoidal voltages?

l. How is a vtvm used to find the gain of an amplifier?

SECTION VI
MULTIMETERS

40. General

a. A multimeter is an instrument incorporating two or more meter circuits and a meter movement in a single case. A typical multimeter (fig. 45) contains voltmeter, ammeter, and ohmmeter circuits using a single meter movement. They may, however, be designed for many specific applications, such as measuring both resistance and capacitance, a-c voltammeters, and d-c voltmeter-millivoltmeters. The multimeters described in this chapter are those used for voltage, current, and resistance measurements.

b. To select the proper circuit for measuring voltage, current, or resistance, either a rotary selector switch or a set of pin jacks is mounted on the instrument panel. The rotary selector switch consists of many sections (wafers) of

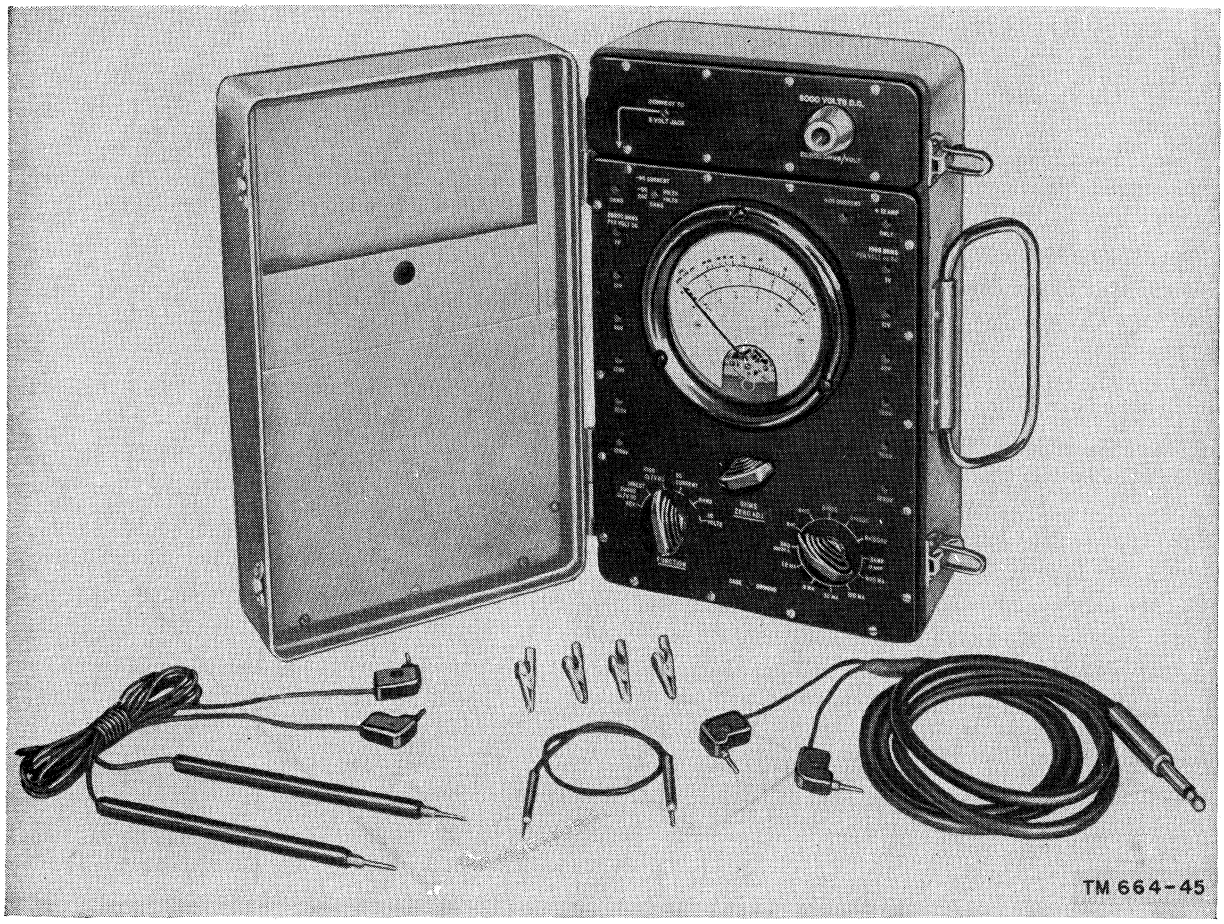


Figure 45. Portable volt-ohm-milliammeter used in measurement of a-c and d-c voltages, direct current, and resistance.

insulating material with switch contacts attached. Each position on the switch corresponds to a particular measuring circuit in the instrument. When the switch is in the d-c voltage position, for example, a contact on each wafer of the switch connects a particular element (meter movement, resistor network, or shunt) into the measuring circuit. In many multimeters, two rotary switches are used, one selecting the measuring circuit, and the other the range. The number of ranges available for the measurement of voltage, current, and resistance varies from meter to meter.

c. When two rotary switches are used, only two pin jacks are necessary on the panel of most multimeters although separate pin jacks may be provided to protect the instrument against damage on the high a-c and d-c voltage ranges. When one rotary switch is used to select the desired measuring circuit, however, separate pin jacks may be needed for each range.

d. For simplicity of reading, most multimeters have three scales, one for resistance measurements, one for d-c volts and milliamperes, and another for a-c volts. The scales usually are provided with a single set of calibration marks and with one or more sets of numerals at the major marks or dimensions. Selection of the individual ranges of measurements to be used determines the multiplying factor to be applied. For example, if the meter d-c voltage ranges are 0 to 10, 50, 250, 500, and 1,000 volts, only three calibrations are required on the indicator scale (fig. 46). The values for the 0- to 10-, 50-, and 250-volt ranges are read directly off the scale. For the 0- to 500-volt range, the 0-to-50 calibration is used, and each reading is multiplied by 10. If a value of 350 volts is being measured, the needle points to 35 on the 0-to-50 scale. Multiplying 35 by 10 gives the true value of 350 volts. Similarly, when measuring resistance with the range selector switch at the R×100 setting, each reading on the ohmmeter scale is multiplied by 100 for the true measured resistance value.

e. In general, there are two multimeters, the volt-ohm-milliammeter, and the electronic multimeter. The volt-ohm-milliammeter combines conventional voltmeter, ammeter, and

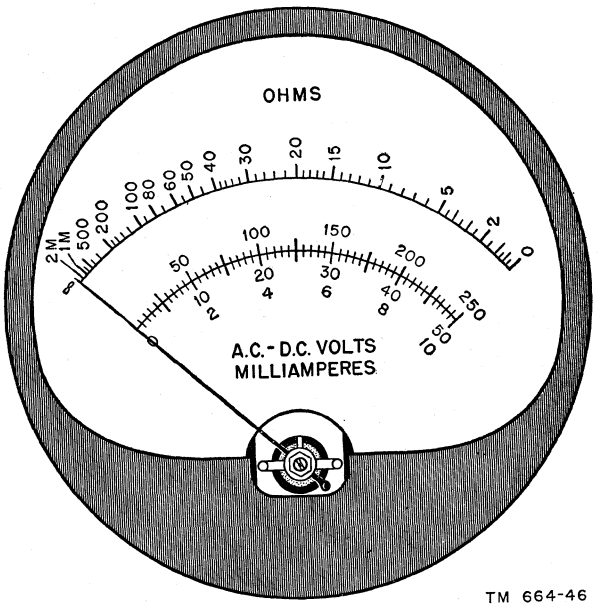


Figure 46. Resistance, a-c, and d-c scales of typical multimeter.

ohmmeter circuits with a d'Arsonval moving-coil meter movement for d-c measurements. For a-c voltage, a rectifier is added to the circuit. The electronic multimeter combines a vacuum-tube voltmeter with conventional ammeter and ohmmeter circuits.

41. Volt-Ohm-Milliammeter

a. GENERAL.

(1) Despite the recent advances in the design and manufacture of meters, the conventional volt-ohm-milliammeter remains the most common equipment for general electrical measurements. Most of these instruments use 50-μa to 1-ma meter movements. The 50-μa meter is used to achieve d-c voltage sensitivities of 20,000 ohms per volt, and is adequate for most d-c measurements, since circuit operation is not greatly affected. Less sensitive meters provide 1,000- or 5,000-ohms-per-volt sensitivity, but care must be taken when using these instruments that circuit operation is not upset. Most a-c voltmeter circuits are designed for 1,000 ohms per volt.

(2) The panel switches and jacks on volt-ohm-milliammeters generally have a standardized arrangement, an example of which is shown in figure 47. The OHMS-AC-DC switch is used to select the unit being measured. The OHMS-ZERO-ADJ knob is used to zero-adjust the meter when ohms are measured. The various jacks around the outer edge are used to select the range of resistance, voltage, or current desired. When the OHMS-AC-DC switch is in the OHMS position one test lead is inserted in the common jack and the other is inserted in the range (R×1, R×10, R×100) desired. The leads are then shorted together and the ZERO-OHMS-ADJ knob is turned until the meter shows full-scale deflection. The unknown resistor then is placed across the two test leads and the value in ohms read directly on the meter scale. When measuring alternating or direct current or voltage, the OHMS-AC-DC switch is placed on the type of voltage or current being measured. The one test lead is inserted in the common jack and the other in the voltage or current range desired. The test leads then are applied across the voltage to be measured or in series with the circuit if current is being measured.

(3) The most common volt-ohm-milliammeters are those which measure only d-c voltage, direct current, and resistance, and those which measure a-c and d-c voltage, direct current, and resistance.

b. D-C VOLTAGE, CURRENT, AND RESISTANCE METERS.

(1) The circuit of a simple volt-ohm-milliammeter used to measure d-c voltage, current, and resistance is shown in figure 48. The circuits and ranges are selected by using pin jacks. For current measurements less than 1 ma, the test leads are plugged into the pin jacks marked 1 MA and COMMON. The current divides between the meter and the shunt, and the meter reading is proportional to the current through it. For currents between 10 and 100 ma, the 100 MA and COMMON terminals are used. Part of the current flows through R_3 and R_4, and the rest of the current flows through R_1, R_2, and the movement. For full-scale deflection, the current through the movement is the same as before, because decreasing the shunting resistance and increasing the resistance in series with the movement causes more current to flow through the shunt and less through the meter.

(2) When measuring voltage with this instrument, the multiplier resistor used depends on the full-scale deflection required. For example, if the voltage to be measured is between 10 and 100 volts, the test leads are plugged into the 100 V and COMMON jacks. The current from the circuit under test then divides between the meter and the shunt resistors, flows through the 100,000-ohm multiplier resistor, and back to the circuit under test. The circuit operation is the same for the other two voltage positions with the exception of the multiplier resistors. Because all the resistors in this meter circuit are fixed, the current through the meter is directly proportional to the voltage across the terminals and can be read directly on the meter.

(3) For resistance measurements, either the 1 MEG jack or the one marked 100,000 OHMS is used with the COMMON jack. Depending on which jack is used, the current from either the 15-volt or the 1.5-volt battery flows through the OHMS-ZERO-ADJ resistor (R_8 or R_{10}), the resistor being measured, the meter and its shunt resistors, the multiplier resistor (R_9 or R_{11}), and back to the battery. The larger the resistor being measured, the smaller the current, and the smaller the deflection of the meter needle. The resistance scale is cali-

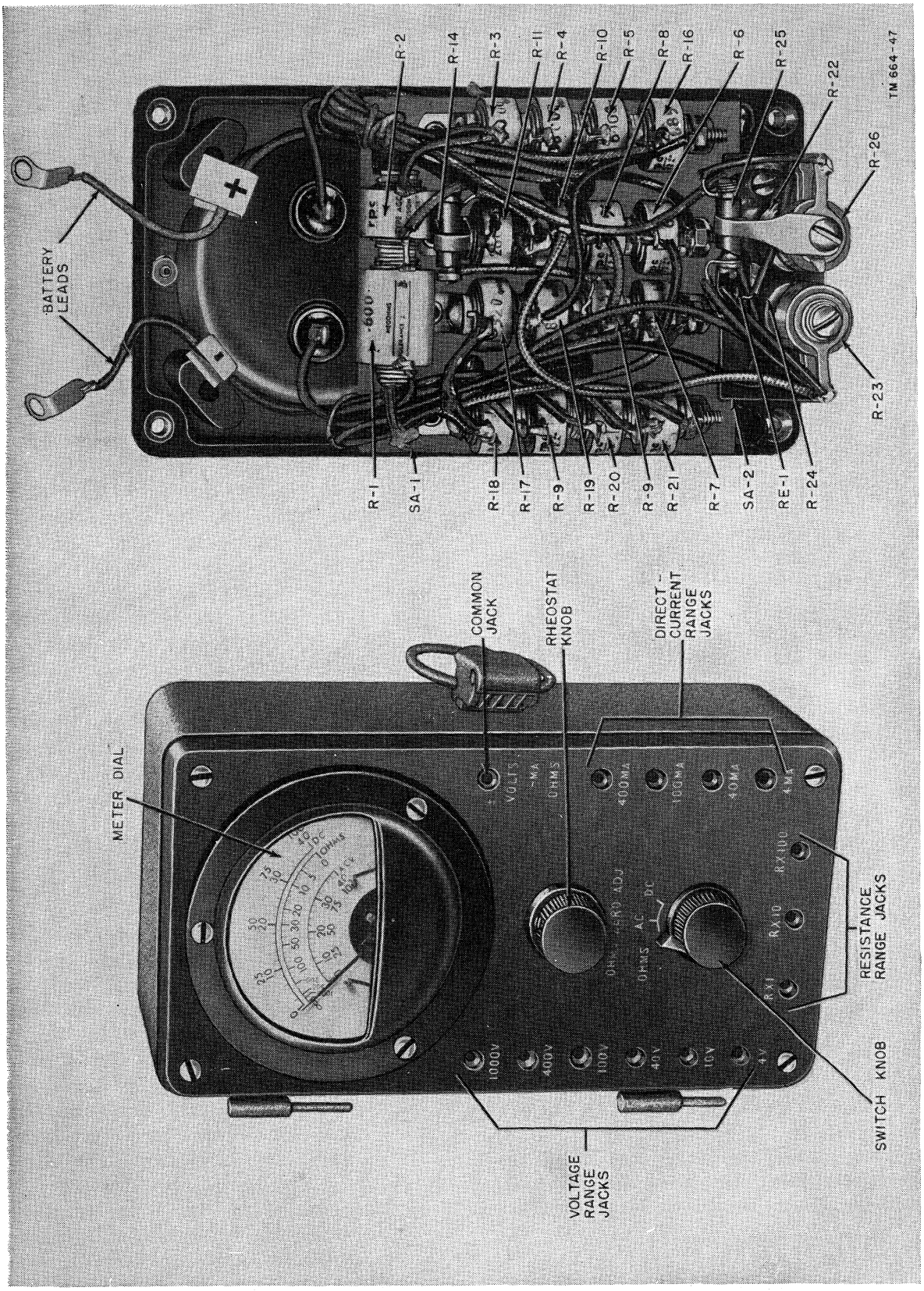


Figure 47. View of front and back panel of simple volt-ohm-milliammeter.

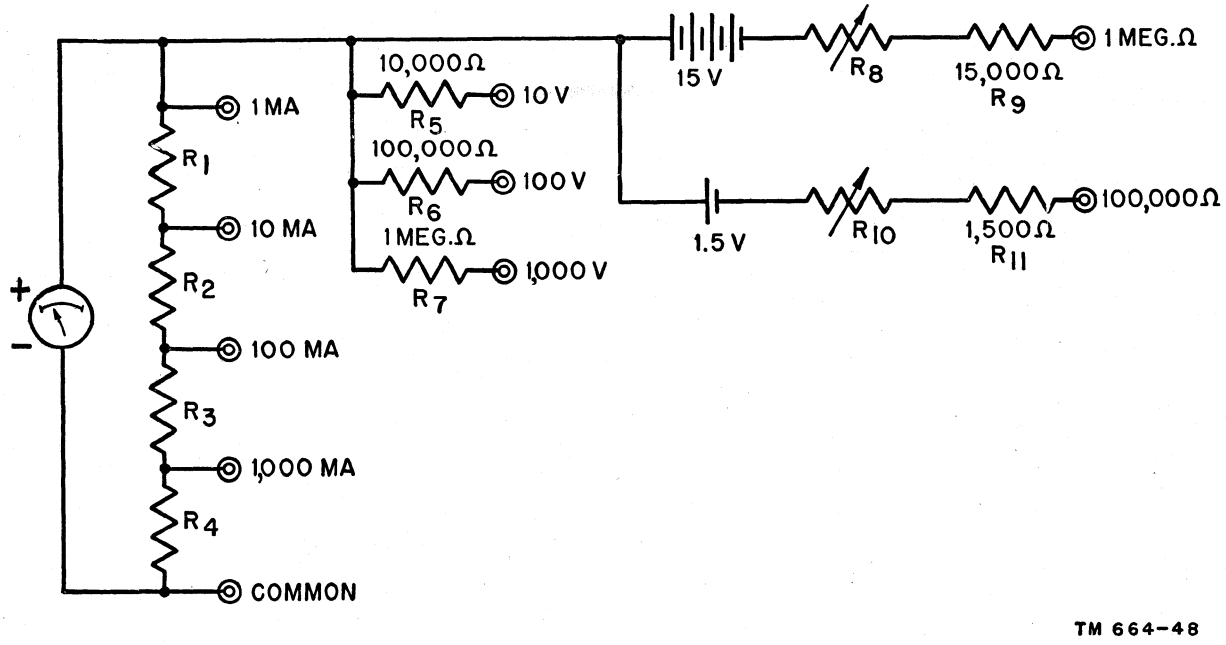


Figure 48. D-c volt-ohm-milliammeter circuit.

brated from right to left, and a small deflection indicates a large external resistance.

(4) The circuit of figure 48 has four direct-current ranges, three d-c voltage ranges, and two resistance ranges. Other meters of the same type may include more resistance ranges than provided here, as well as an increased number of voltage ranges. The circuit described here is limited in its application to d-c measurements. To extend its use to include a-c measurements, some type of rectifier circuit must be added.

c. A-C AND D-C VOLTAGE, DIRECT CURRENT, AND RESISTANCE METERS.

(1) Figure 49 is the circuit of a volt-ohm-milliammeter capable of measuring a-c and d-c voltages, direct current, and resistance. The voltage-measuring circuit consists of two sets of series multiplier resistors, one for d-c voltages, and the other for a-c voltages. When measuring d-c volts, the circuit selector switch is turned to the VOLTS position. One test lead then is inserted in the jack labeled COMMON and the other is plugged in the D-C VOLTS jack of the range desired. The meter movement is now shunted by the string of resistors immediately below it in the diagram, and is in series with the d-c multiplier resistors labeled D-C VOLTS.

(2) For a-c voltage measurements, the a-c multiplier resistors are used with their corresponding jacks. The germanium crystal is a half-wave rectifier feeding pulsating dc to the meter and its shunt. One test lead is inserted into the jack for the range desired and the other is inserted into the COMMON jack. When the polarity of voltage at the range jack is positive, current flows through the meter circuit. When the current reverses and the COMMON terminal is positive, current flows through the large resistor, R_R, and the multiplier resistor. This return circuit on the negative half-cycle is necessary to keep high negative voltages off the rectifier crystal. Although the resistance of the crystal

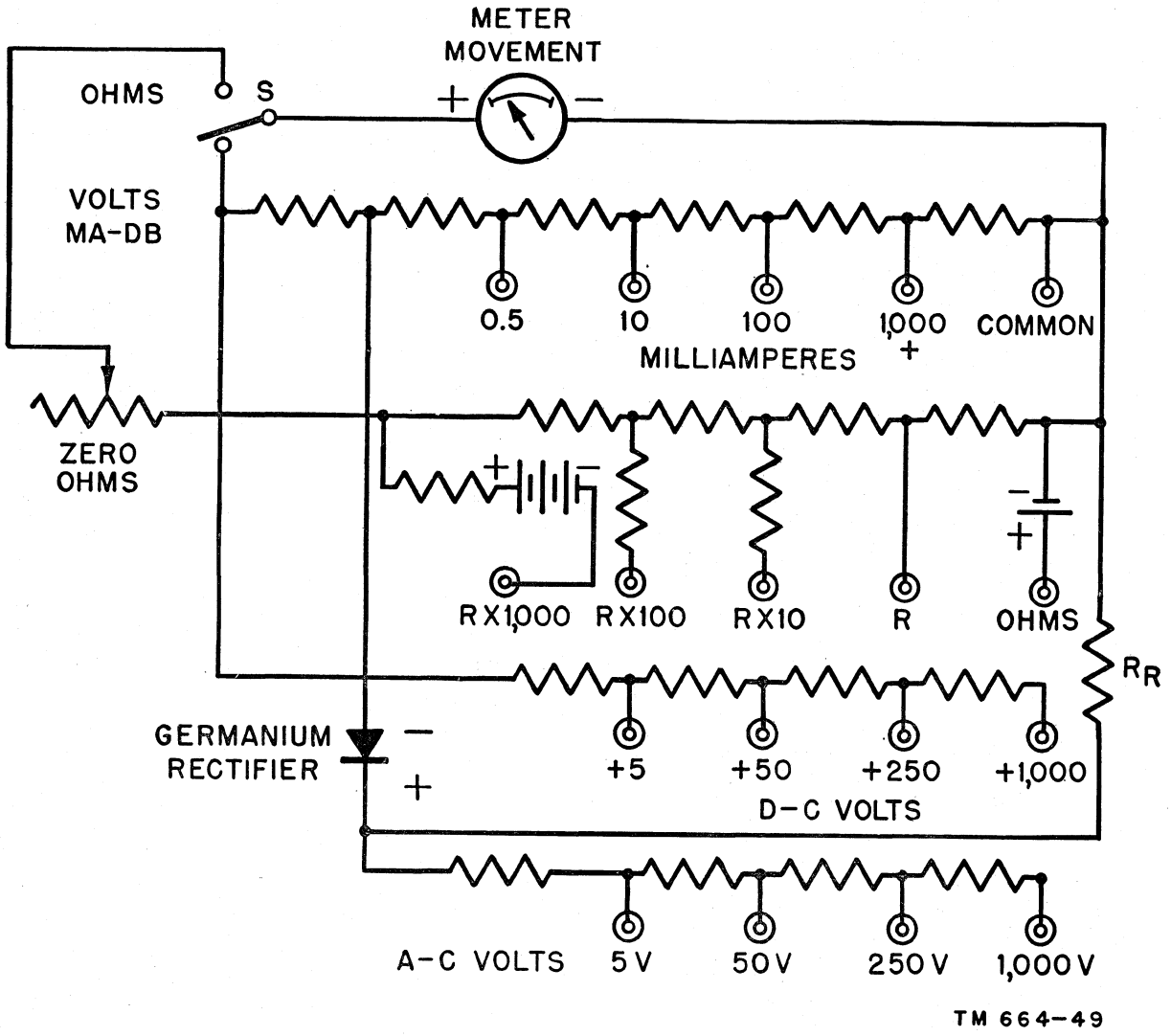


Figure 49. Basic circuit of a-c, d-c volt-ohm-milliammeter.

rectifier on the negative alternation is large (approximately 60,000 ohms), it still passes a small current when its polarity is reversed. Therefore, if R_R is not included in the circuit excessive voltages may damage the crystal.

(3) Current and resistance measurements are made in the manner described for the circuit of figure 48. When the R×100 jack is used, an additional battery, generally about 4.5 volts, provides enough current through the circuit for a convenient meter reading. For all resistance measurements, the test leads are plugged in the jack labeled OHMS and either the R, R×10, R×100, or R×1,000 jack, depending on the range desired.

42. Electronic Multimeter

a. GENERAL. The electronic multimeter is a vacuum-tube voltmeter circuit used to measure a-c and d-c voltages and resistance. It is similar to the vtvm in appearance, and the panel switches and jacks are the same as those used in the volt-ohm-milliammeter.

b. TYPICAL CIRCUIT.

(1) The block diagram in figure 50 is that of an electronic multimeter capable of measuring a-c and d-c voltages and

resistance. For a-c voltage measurements, the a-c rectifier probe is used and pulsating dc output is fed to selector switch S_1. For d-c voltage measurements, the d-c isolating probe is used. Selector switch S_1 is a six-pole, six-position wafer switch that turns the power on and selects the type of measurement. Range switch S_2 is a four-pole, nine-position wafer switch used to obtain the desired range for each type of measurement. A d-c degenerative amplifier maintains a high input resistance and provides a low output resistance to match the resistance of the meter movement. The balancing diode, V_2, is used to buck out the contact potential of the rectifier tube in the a-c probe. The power supply furnishes d-c voltages to operate the vacuum tubes used, and the battery is part of the ohmmeter section of the multimeter.

(2) The six sections of the function selector switch are shown in the upper left portion of the complete schematic diagram in figure 51. The ON-OFF switch, S_1-7, is in the primary circuit of the power supply transformer, and the four sections of the range switch are shown in the lower left portion. The range switch is set on the 2_V-R$\times$1 position. Section 1 of the range switch controls the balancing voltage from V_2 on a-c measurements, section 2 controls the ohmmeter circuit attenuator, and section 4 is the voltmeter section attenuator. The two-tube amplifier, V_3 and V_4, is coupled through V_5 and the low-resistance neon glow tubes, V_6 and V_7, to the indicating meter.

(3) The method of connecting the ohmmeter circuit to the amplifier is shown in figure 52. The range switch is set to position 3 (R$\times$100). In this position, R_{34}, a 3,000-ohm resistor, is shunted across the amplifier and meter circuit. The voltage from the batteries is divided across R_{34} and the unknown resistor, and the vtvm is calibrated in terms of the voltage across R_{34}. R_3 is used to adjust the indicating meter needle to 0 before resistance measurements are made.

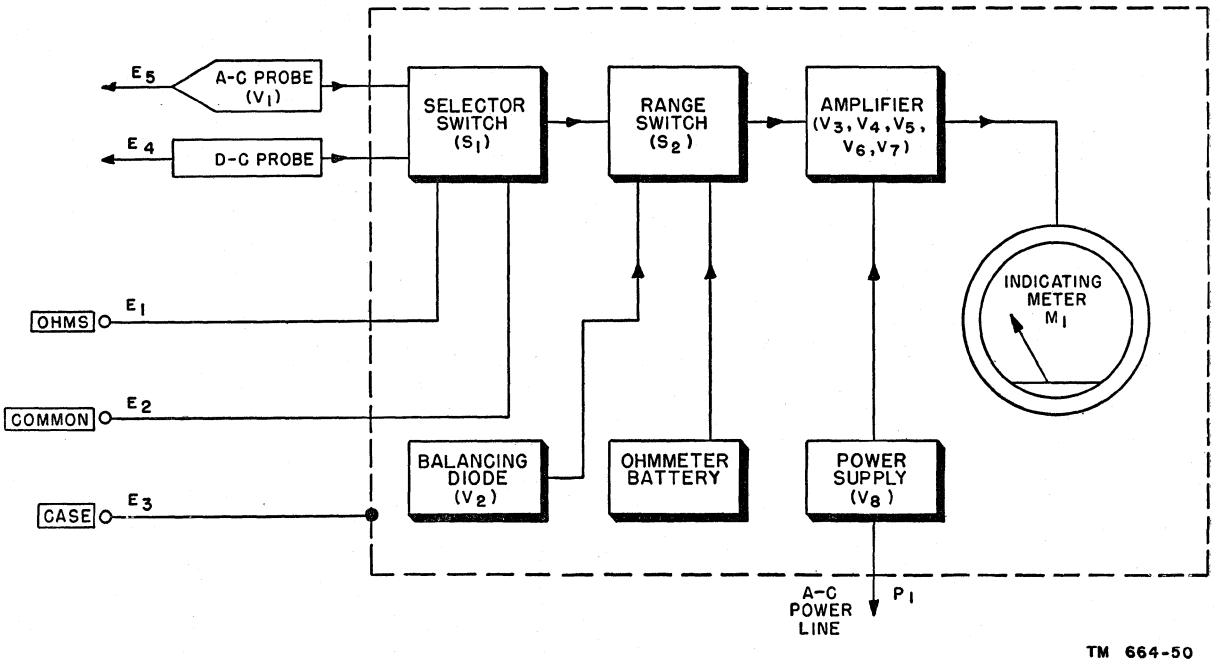


Figure 50. Block diagram of typical electronic multimeter.

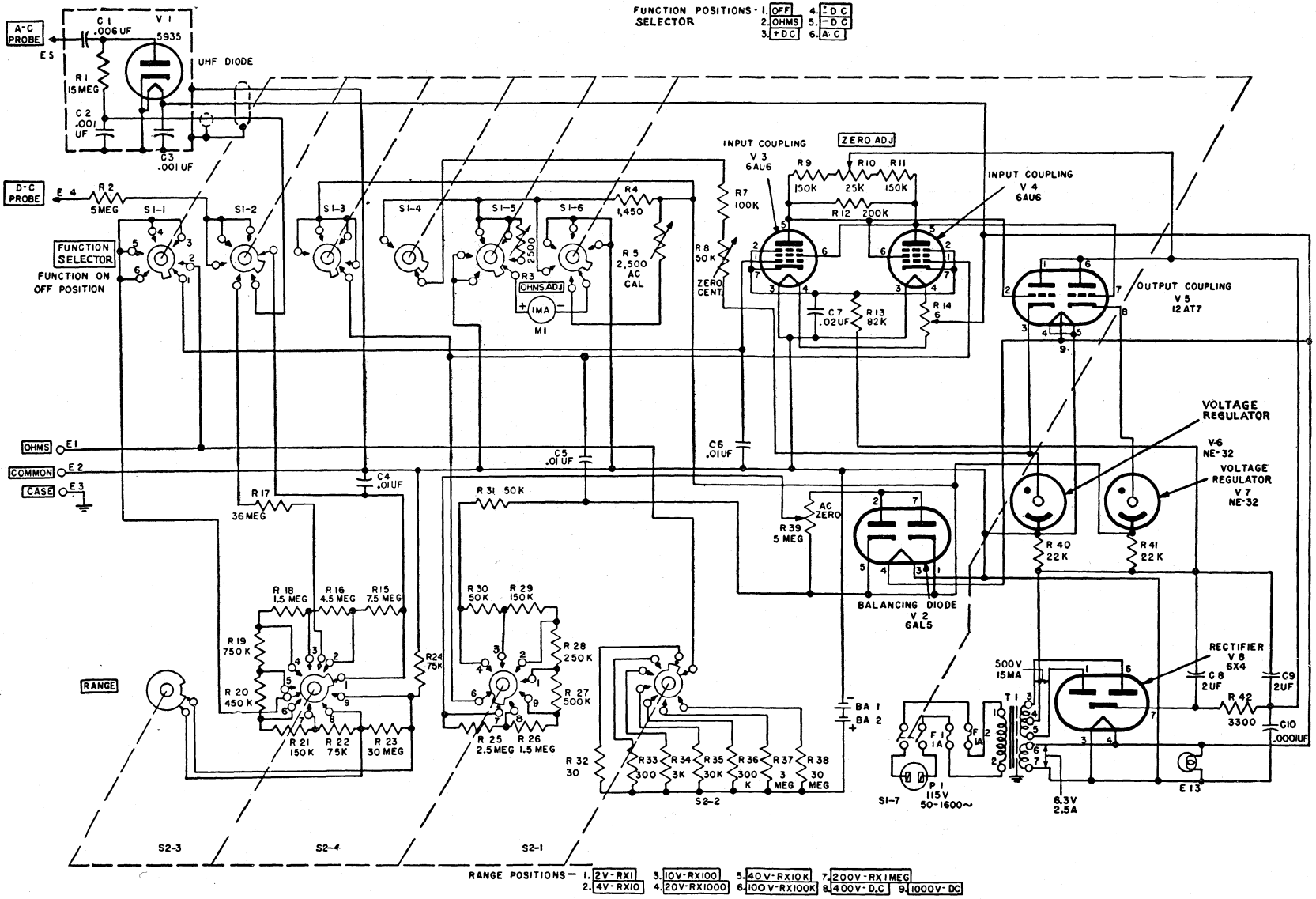


Figure 51. Schematic diagram of typical electronic multimeter.

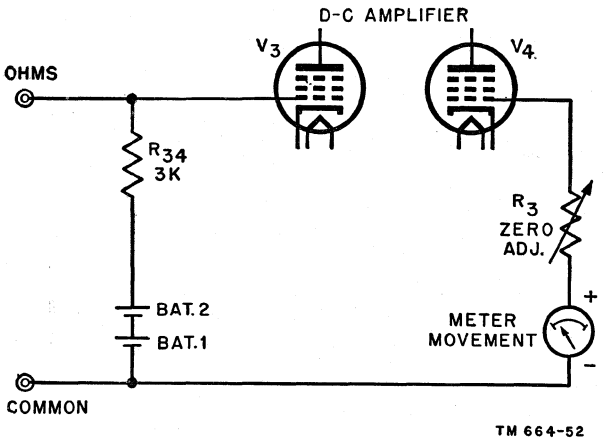


Figure 52. Simplified schematic of ohmmeter circuit for multimeter shown in figure 51.

(4) For d-c voltage measurements, a circuit similar to the simplified one in figure 53 is used. The d-c probe contains the 5-megohm resistor used to isolate the d-c section of the multimeter and minimize the loading effect of the voltmeter on the circuit under test. The input voltage is taken off the portion of the input attenuator from R_{18} to R_{22}, and is fed to the control grid of V_3. The indicating meter reads a voltage that is proportional to the input voltage. The negative terminal of the indicating meter is connected to the common terminal of the multimeter for the +d-c and ±d-c measurements. The positive terminal of the indicating meter is connected to COMMON for —d-c and a-c positions of the function selector switch. Section 4 of the function selector switch in figure 51 applies .5 ma through the indicating meter on the ±d-c ranges so that the meter reads midscale for 0 volts. Section 3 of S_2 shorts out resistor R_{23} on all ranges except the 1,000-volt setting. The total input resistance for all voltage ranges except the 1,000-volt range is 20 megohms (including the probe resistor). At the 1,000-volt setting the total input resistance is 50 megohms.

(5) A-c voltage measurements are accomplished by first rectifying the ac and then applying the resultant pulsating dc to attenuator S_2-4. A portion of this voltage then is taken off the attenuator and fed to the d-c amplifier (fig. 54). The voltage used to balance out the contact potential of the probe diode, V_1, is taken from the balancing-diode voltage divider and applied to the control grid of V_4. This voltage is adjusted to equal the contact potential of V_1 applied to the grid of V_3. The instrument is calibrated to read rms volts for sinusoidal voltages. The input impedance of this instrument on all a-c ranges is 6 megohms, with a shunting capacitance of 2 micromicrofarads.

(6) When measuring current on the vtvm, only the indicating meter and the necessary shunt circuits are used. The addition of an attenuator in parallel with the meter movement makes the meter capable of measuring direct current. Generally, the attenuator is used for current measurements from .1 ma to 1,000 ma. For measurements from 1 to 10 amperes, the total attenuator resistance is in series with the meter movement, and a small resistor is shunted across the input. A separate set of pin jacks generally is used for current measurements.

c. OUTPUT POWER RANGES. The a-c output power of an audio or power amplifier can be obtained by measuring the a-c voltage across the output load resistor, squaring this value, and dividing by the value of the load resistance. Electronic multimeters capable of measuring a-c voltages usually have a scale which translates output voltage readings into relative power values in terms of decibels. See chapter 8.

43. Using Multimeter

a. GENERAL PRECAUTIONS.

(1) Before using any multimeter, carefully read and observe all of the instructions covering its use in the instruction book furnished with it. When using any instrument, the

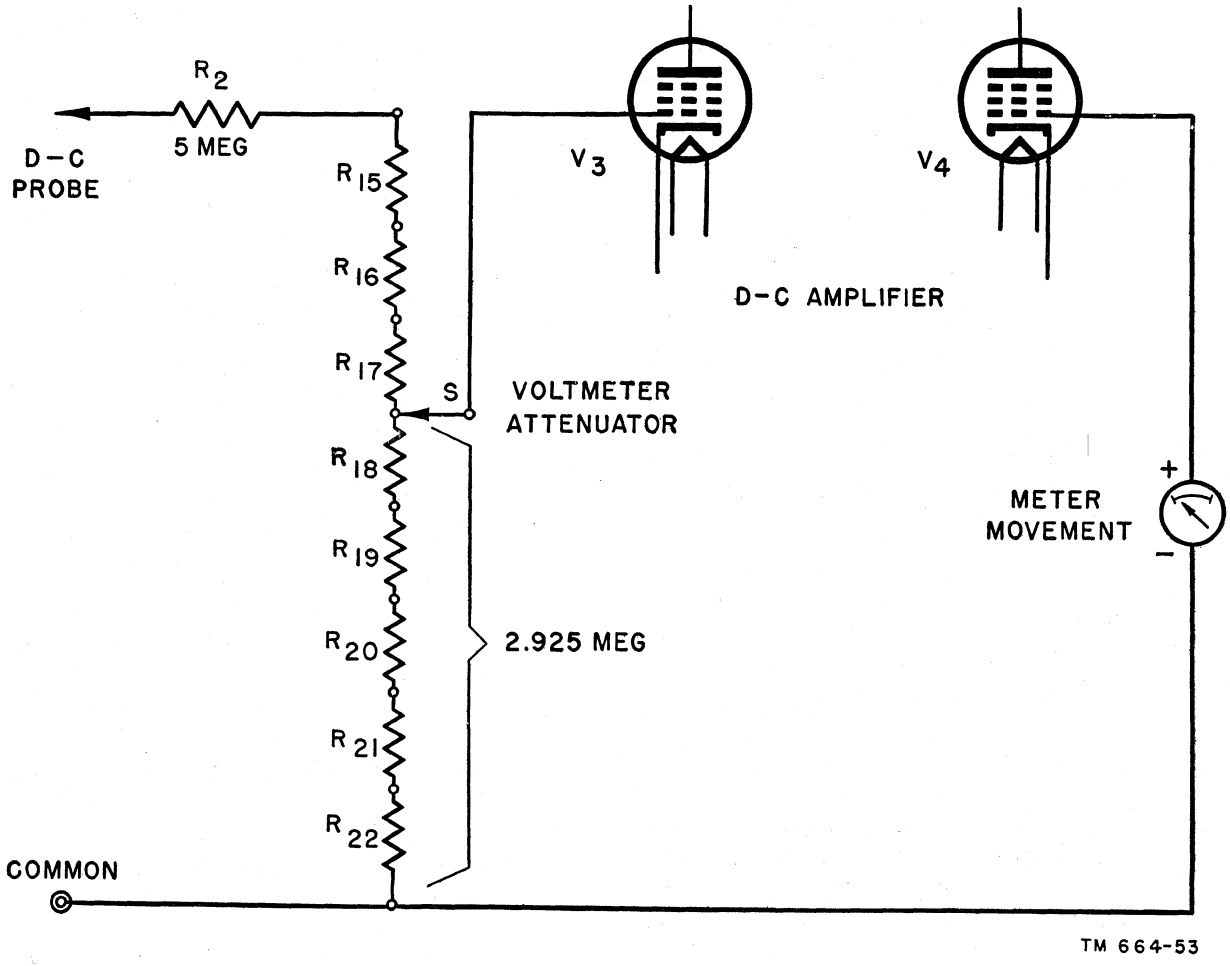


Figure 53. Simplified d-c voltage-measuring circuit of multimeter shown in figure 51.

front panel, particularly the area around the jacks and terminals, should be clean and dry. This prevents surface leakage which acts as a shunt and may cause an appreciable error in readings on the more sensitive ranges of the instrument.

(2) The following practices should be observed when using a multimeter on any of its ranges:

(*a*) When the instrument has a zero adjustment, the needle should be adjusted to 0 before any readings are taken. Electronic multimeters generally have two zero-adjust knobs on the front panel. One knob is used for setting the voltmeter to zero indication by balancing the d-c amplifier, and the other for setting the ohmmeter to indicate full-scale value with the test leads open-circuited. Multimeters of the volt-ohm-milliammeter variety do not require external zero-adjust controls for their voltage and current measuring ranges. Panel zero-adjust controls for ohmmeter circuits using batteries are always necessary to compensate for the degeneration of the batteries. If the needle cannot be brought to 0 by means of the panel adjustment knobs, additional controls usually are available within the instrument. Instructions for adjusting these controls are found in the instrument manual.

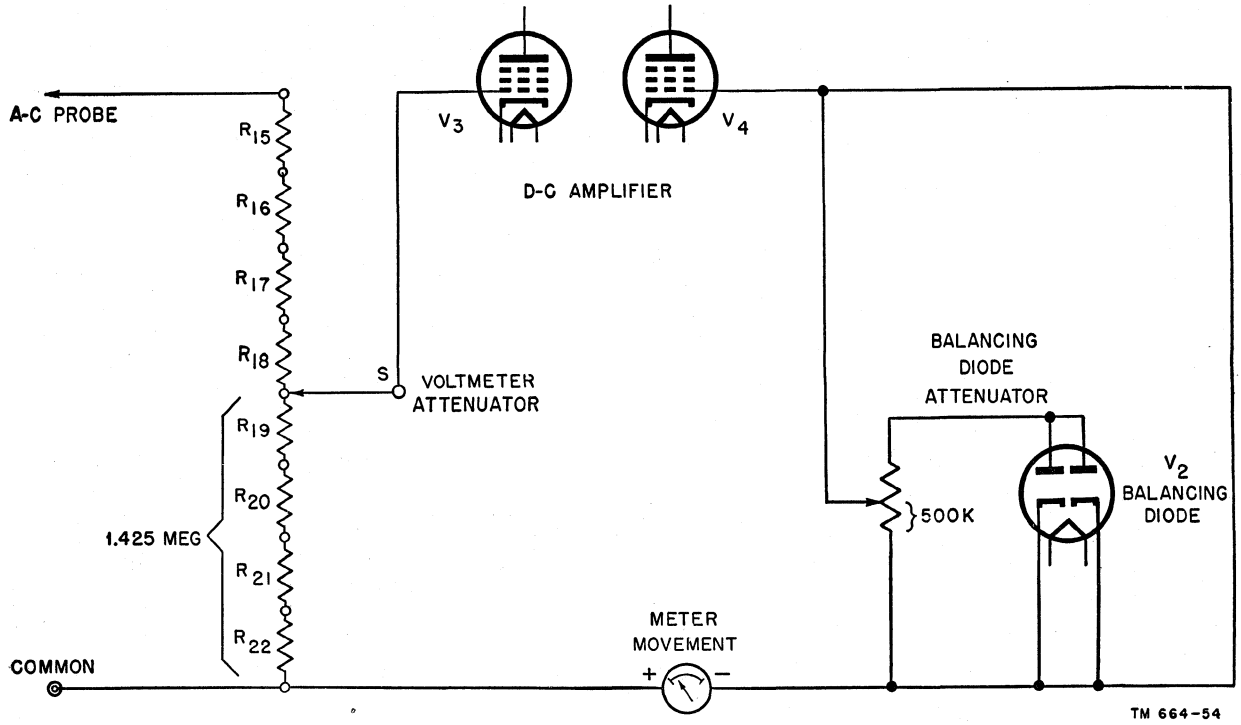


Figure 54. Simplified schematic of a-c voltage-measuring circuit of multimeter shown in figure 51.

(*b*) Set the range switch to the highest range for voltage or current measurements before making the measurement. For example, when measuring d-c voltage with a meter whose d-c voltage ranges are 0 to 10, 0 to 50, 0 to 250, 0 to 500, and 0 to 1,000, the initial range setting on the meter should be for the 0 to 1,000 range. This will protect the meter against damage from voltages which are higher than expected.

(*c*) When using electronic multimeters, the voltage and frequency of the power source must be within the values given in the equipment manual accompanying the instrument.

(*d*) Before making resistance measurements, be sure that no voltage exists in the circuit under test. *Discharge all capacitors.* The presence of any voltage through the external resistance in addition to the voltage of the battery in the ohmmeter circuit can damage the meter.

(*e*) The rotary switches on the front panel generally are not continuously rotatable. *Do not try to force them beyond the first or last position.*

(*f*) Observe all of the precautions listed in the previous chapters of this manual for the prevention of damage to meters and for obtaining accuracy of readings.

b. FUNCTIONS. The multimeter is used wherever a voltmeter, ammeter, or ohmmeter is needed for trouble-shooting electronic equipment. Voltage and current measurements are made on a circuit to locate the part in which a defect exists. The ohmmeter section of the multimeter then is used for checking the value of resistors, checking capacitors for leakage, and locating grounds, short circuits, and open circuits. *The ohmmeter tests must be made with no power applied to the circuit under test.*

44. Summary

a. A multimeter is a single instrument consisting of a case, two or more types of measuring circuits, and an indicating meter.

b. The indicating meter used in multimeters generally has a d'Arsonval moving-coil movement.

c. The two basic multimeters are the volt-ohm-milliammeter and the electronic multimeter.

d. The volt-ohm-milliammeter uses conventional voltmeter, ammeter, and ohmmeter circuits as described in chapters 2, 3, and 4.

e. Electronic multimeters are a combination of a vacuum-tube voltmeter with conventional ammeter and ohmmeter circuits.

f. The various measuring circuits of a multimeter usually are selected by means of a rotary switch and a set of pin jacks for the test leads.

g. Two scales are necessary on the indicating meter. One scale is calibrated for the voltage and current ranges of the instrument, the other for the resistance ranges. The various ranges for each type of measurement are selected by either a rotary switch or pin jacks.

h. Volt-ohm-milliammeters generally have a sensitivity of 1,000 or 20,000 ohms per volt for voltage measurements.

i. A d-c volt-ohm-milliammeter uses a variable resistor to shunt the meter when current measurements are taken; a set of series multiplier resistors plus the shunting resistance for voltage measurements; a battery, a series resistor, and the meter-shunting resistor for resistance measurements.

j. To measure a-c voltage with the volt-ohm-milliammeter, a copper-oxide or germanium-crystal rectifier is inserted in series with the meter movement. The indicating meter gives the *average* value of the resultant pulsating dc and is calibrated in terms of *rms* volts.

k. A typical electronic multimeter consists of an a-c rectifier probe, a d-c isolating probe, a shunt and series resistance network, a d-c amplifier, a d'Arsonval-type meter movement, and a power-supply circuit. A conventional ohmmeter circuit is included to measure resistance.

l. When using a multimeter, observe all the precautions listed in the equipment manual, as well as all the other precautions necessary for protection of the meter.

45. Review Questions

a. What is a multimeter?

b. What is the function of the rotary selector switches on the panel of a multimeter?

c. If the d-c voltage scale of a multimeter is calibrated with values for 0 to 10, 0 to 50, and 0 to 250 volts, explain how a 300-volt reading can be made if the range selector switch has positions of 10, 50, 250, and 500 volts.

d. What are the two basic types of multimeters? What is the difference between them?

e. Draw the circuit and explain the operation of a typical d-c volt-ohm-milliammeter.

f. Add an a-c voltage measuring circuit to the meter drawn in answer to question 5 and explain its operation.

g. What are the major elements of the a-c voltage measuring circuit of a typical *electronic* multimeter? Draw a circuit diagram showing these elements directly connected for a-c voltage measurements.

h. What voltage range setting of the range selector switch of a multimeter is used for the initial voltage measurement in a circuit?

i. How is the ohmmeter section of a multimeter adjusted to read the correct resistance for all succeeding measurements?

SECTION VII
TUBE TESTERS

46. Introduction

The tube tester measures the important operating characteristics of an electron tube and indicates, approximately, whether the tube is good. Because of the quickness of this operation, use of the tube tester often is preferable to the substitution method of testing tubes, which consists of replacing a tube thought to be defective with a good tube of the same type, the assumption being that if the circuit then operates properly with the new tube, the first tube is bad.

a. TUBE TYPES. Electron tubes are designated, according to their function and the number of active elements they contain, as diodes, triodes, tetrodes, pentodes, multiunit tubes, cathode-ray tubes, gas tubes, and special tubes.

(1) A diode is an electron tube with two electrodes, a cathode, and a plate. When the cathode is heated to the point that electrons are emitted, and the plate is positive with relation to the cathode, there is a flow of electrons from the cathode to the plate. Tube testers generally test diodes for emission and short circuits.

(2) Triodes, tetrodes, and pentodes have an additional one, two, and three electrodes, respectively. These additional electrodes are used to control the electron emission, space charge, or secondary emission which occurs as a result of the emission of electrons from the cathode and their bombardment of the plate. The control of the electron emission by these additional electrodes, called grids, makes possible the use of the electron tube as an amplifier or oscillator. Tube testers generally test triodes, tetrodes, and other multielement tubes for mutual conductance, short circuits, gas, and sometimes for emission. To test for cathode-heater leakage and noisy tubes, other tests are used.

(3) A multiunit electron tube consists of two or more separate and complete sets of electrodes inclosed in a single tube envelope. Each set of electrodes has its own tube-socket connections or pins, and fulfills a specific function in the circuit in which the tube is used. Examples of multiunit electron tubes are the duo-diode, a tube envelope containing two plates and two cathodes, and the duo-diode-triode, in which two diodes and a triode are contained in the same tube envelope. Each unit of a multiunit electron tube operates in exactly the same manner as if it were in a tube envelope by itself. Multielement tubes require separate tests for each unit.

(4) Cathode-ray tubes are of two types. One is the long funnel-like tube in which electrons emitted from a cathode in the neck of a tube are focused by adjusting electrodes to strike and, consequently, produce light on a fluorescent screen on the face of the tube opposite the cathode. The other type is the tuning indicator or electric-eye tube. This is a standard-size tube containing an electron emitter, a circular target coated with a fluorescent substance, a vane-like electrode between the target and the emitter, and a control grid between the lower part of the emitter and the plate. The electrons from the emitter hit the target electrode everywhere

except in the vicinity of the vane, causing a ring of light. The size of the shadow which crosses the ring where the vane is situated depends on the voltage on the control grid.

(5) Gas tubes are diodes, triodes, or tetrodes containing a gas. The gas keeps the electron flow between the cathode and plate to a minimum for all values of potential difference between them, up to a certain value known as the ionizing potential. When this value is reached, the gas ionizes, breaking up into electrons and positive ions, and electron flow in the tube increases rapidly to a very high value.

(6) Many other special tubes are designed, for specific purposes. Most of these cannot be tested with the ordinary tube tester.

(7) In general, the base of a receiving tube is one of eight standardized types, some of which are shown in figure 55. To assure that each pin on the base is set in the proper socket on the equipment, one of the following methods has been used:

(*a*) Some of the pins on the base are made larger in diameter than others so that the tube can be placed in the socket in only one way.

(*b*) The pins are arranged on the base in such a manner that the spacing between pins corresponds to the spacing between holes on a particular socket.

(*c*) A keyed plug is included on the bottom of the base which fits in a notched hole in the center of the socket.

(*d*) A device is placed on the base of the tube to lock the tube to its socket once it is fitted in the socket properly. This locking device consists of a circular notch toward the bottom of the keyed shaft, and a spring clip on the socket that fits in this notch. Tubes having this device are called lock-ins or loctals.

b. COMMON ELECTRON-TUBE DEFECTS. The operating life of an electron tube depends on the circuit in which it is used, the climate, and the handling it receives. If the average receiving tube is not overdriven or required to operate continuously at maximum ratings, it will operate satisfactorily for 2,000 hours or more before the filament burns out. If it is located in a circuit where the current is relatively low, it will last longer than if it is required to pass high currents. Electron tubes used in hot, humid climates where fungi and excessive moisture cause corrosion become defective sooner than tubes used in temperate and cold climates. When the electron tube is used in mobile or airborne equipment, shock and vibration loosen the internal connections and cause electrode breakage and short circuits. Other tube defects are cathode-heater leakage, excessive gas in vacuum-type electron tubes, and nonuniform electron emission by the cathode. Defective tubes are indicated by such failures as no filament light, insufficient or excessive plate current, gas flow in tube, and internal arcing.

c. TYPES OF TUBE TESTS. In general, tube testers perform four electron tube tests: the emission test, the mutual-conductance test, the test for short circuits, and the test for excessive gas.

(1) The emission test measures the amount of electron emission from the cathode under standard conditions. If the cathode heater is open, there is no emission. If the cathode or cathode coating is nearly exhausted, emission is subnormal.

(2) The mutual-conductance test measures the mutual conductance, G_m, of an electron tube when typical operating voltages are applied to its electrodes. The mutual conductance is measured and compared with the ratings of the manufacturer, and the quality of the tube is indicated. Most of the mutual-conductance tube testers are calibrated to read the G_m of the tube in terms of good, bad, or weak.

(3) Short circuits between electrodes in a tube are found by connecting one electrode to one side of a power supply through a neon bulb, and all or some

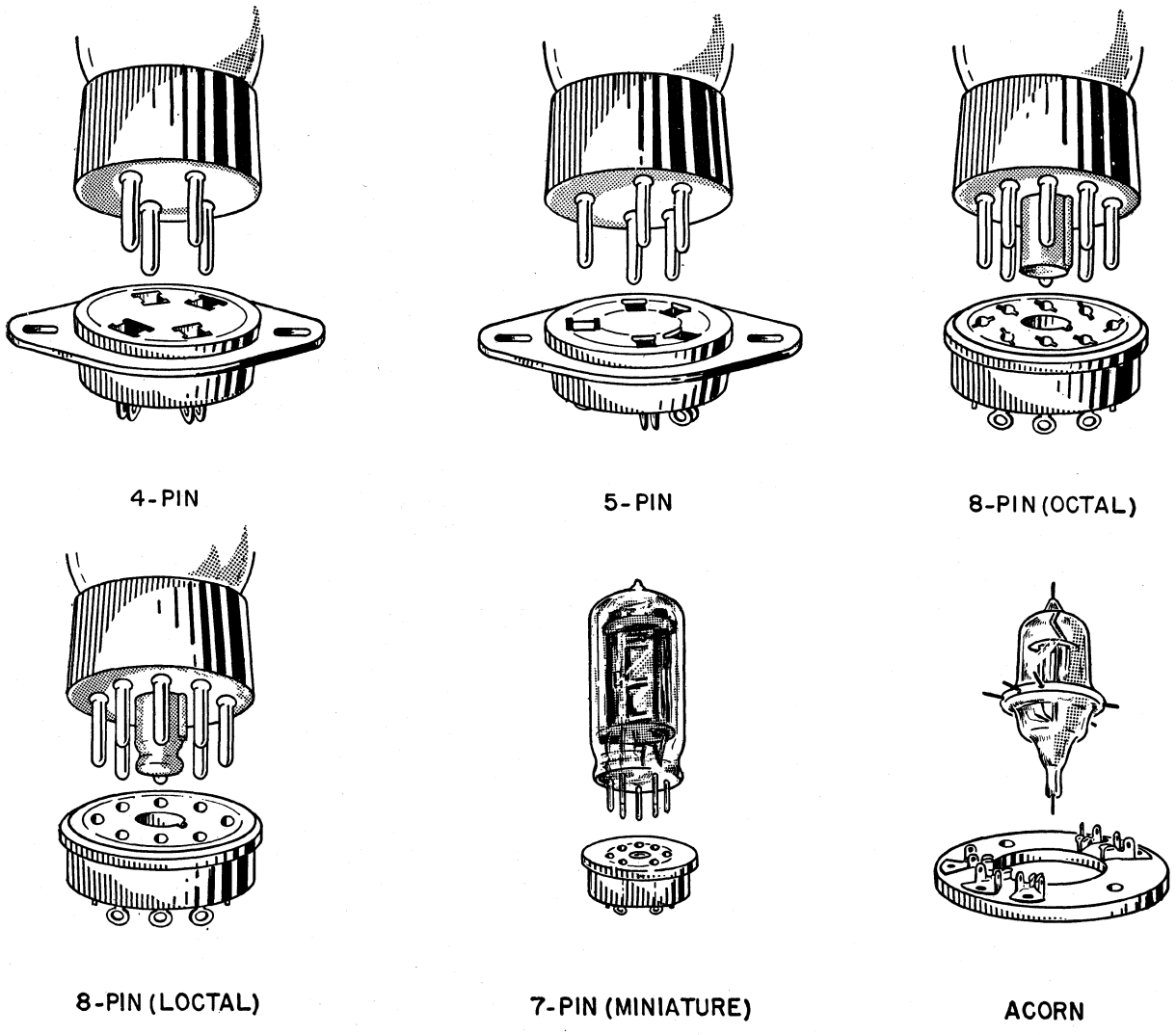


Figure 55. Receiving tube bases and corresponding sockets.

of the remaining electrodes to the other side of the power supply. If two electrodes are touching, or connected within the tube, the neon bulb glows because there is a complete circuit through the electrodes.

(4) To test for excess gas, normal operating voltages are applied to the various electrodes of the tube, and the plate current is recorded. A biasing resistor then is placed in the control-grid circuit. If gas is present, the introduction of this resistor makes the grid more positive, and there is an appreciable grid current and an increase in plate current.

47. Basic Tube Testing

a. TESTING BY SUBSTITUTION.

(1) When tube failure is suspected, substitution of a tube known to be good is a simple method of determining the quality of the tube in question. For

example, if a receiver-amplifier tube is weak, the output as heard from the loudspeaker or earphones is weak. When this tube is replaced with one known to be good, the output increases, indicating that the first tube is relatively poor. It may be possible to use this tube in another circuit if it is not too weak, but this is not good practice.

(2) When a radio receiver using avc has low sensitivity, the avc rectifier tube should be checked. This condition also can be caused by an open resistor in the avc circuit or a defective capacitor, but replacement of the avc rectifier tube quickly reveals whether the tube or another component in the circuit is faulty. Substitution testing cannot be used to advantage to locate more than one faulty tube in a single circuit. If both an i-f amplifier tube and an r-f amplifier tube are defective in a single receiver, replacing either one does not make the receiver operative. When all of the tubes are replaced, and the receiver operates, there is no way of knowing which tubes were defective. Use of a tube tester under these conditions saves time.

b. TESTING EMISSION.

(1) If the cathode-to-plate emission in an electron tube is low, fewer electrons reach the plate, plate current is low, and the tube is not an efficient amplifier. To test the emission of an electron tube, the tube is connected as a half-wave rectifier (fig. 56). The primary of the transformer is connected across a 110-volt a-c line. The plate and all of the grids of the tube are connected to one side of the secondary of a transformer. A current meter and resistor, R, are placed in series with the tube and the entire circuit is connected across the transformer secondary. All of the grids and the plate are at the same potential in respect to the cathode, and the tube acts as a diode half-wave rectifier, conducting current only during that half-cycle input when the grids and plate are positive in respect to the cathode. The amount of current flowing in the circuit during this half-cycle is an indication of the cathode emission.

(2) The current measured by the meter in this circuit is pulsating dc. When a diode, which normally operates with small current loads, is being tested, the voltage across the tube must be kept within safe limits. Resistor R must be adjusted to its full value of 5,000 ohms, since abnormal emission can damage the cathode or the plate. The control grid of multigrid tubes is positive in respect to the cathode during the current-flowing half-cycle, causing a large cathode-to-plate emission unless R is large enough to keep the tube current within safe limits. The filament of the tube under test receives its voltage from a separate secondary winding of the transformer.

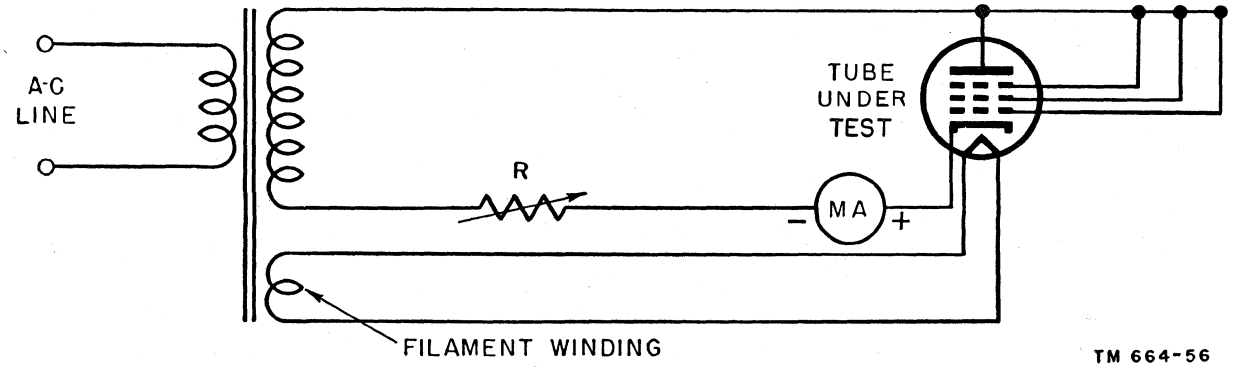


Figure 56. Circuit for measuring cathode emission.

c. TESTING MUTUAL CONDUCTANCE.

(1) The mutual-conductance test supplies more information about the quality of a multigrid electron tube than the emission test. Mutual conductance, sometimes called grid-plate transconductance, is the ratio of the change in plate current to the change in control-grid voltage with all other tube-element voltages constant. The transconductance is measured in *mhos*, the unit of conductance; however, this quantity is so small that it is expressed in micromhos. The equation representing this is:

$$G_m = \frac{\triangle I_p}{\triangle E_g}$$

where G_m is the mutual conductance in micromhos, $\triangle I_p$ is the change in plate current in microamperes, and $\triangle E_g$ is the change in control-grid voltage in volts. When the grid voltage is changed 1 volt positive or negative, the amount of current change in microamperes is equal to the amount of mutual conductance in micromhos. For example, if a tube in an amplifier circuit has a mutual conductance of *1,500 micromhos*, changing its grid bias 1 volt positive or negative causes an increase or a decrease in plate current of *1,500 microamperes*. The mutual conductance of a triode varies with the plate voltage, plate current, and grid bias. The mutual conductance of a pentode is less affected by plate-voltage changes but does vary with screen voltage, plate current, and grid bias.

(2) To tell whether a tube is good or bad, the mutual conductance as indicated by the tester is compared to the mutual conductance rating specified by the manufacturer. To use this rating as a standard, the same plate, screen, and grid-bias voltages must be applied as were used by the manufacturer when establishing the rating. When the mutual conductance is much less than the rating of the manufacturer, the tube will not amplify properly an input voltage applied to its control grid, and it should be discarded.

(3) Two tests—the static and the dynamic—are applied to an electron tube to find the mutual conductance. In the static test, the d-c bias on the grid of the tube is changed and the resultant change in the steady plate current is measured with a current meter (fig. 57). With switch S in position 1, a bias negative with relation to the cathode is applied to the grid of the tube, and plate current flows. When the switch is thrown to position 2, the grid bias is made less negative and the plate current increases. When such a circuit is used to test different electron tubes, provision must be made to make the plate and grid voltages adjustable, allowing typical operating voltages to be applied. Since the mutual conductance of a tube varies with the d-c grid bias, the shift in bias must be small, or the mutual conductance will not be the actual value for the tube.

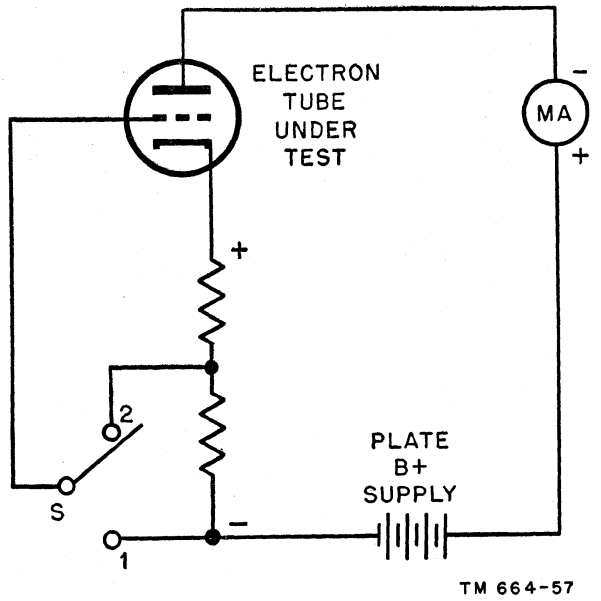


Figure 57. Circuit for measuring mutual conductance of electron tube by static method.

(4) The dynamic method for finding mutual conductance uses a circuit which applies an a-c signal to the control grid in addition to the operating d-c grid bias (fig. 58). The tube under test serves as the load for the full-wave rectifier circuit. The milliammeter is connected across R_m, a center-tapped resistor, and the primary of the transformer to the a-c line. When E_g, the bias on the grid of the tube under test, is some fixed value, the circuit operates as a simple full-wave rectifier. When plate P_2 is positive, there is an electron flow through the upper half of resistor R_m, and the d-c meter needle tends to deflect in one direction. When the voltage across the secondary reverses and plate P_1 is positive, the electron flow is through the lower half of R_m, and the needle tends to deflect in the opposite direction. The meter needle cannot follow these variations occurring at the line frequency and stays in the 0 position, since the forces on it are equal and opposite in direction.

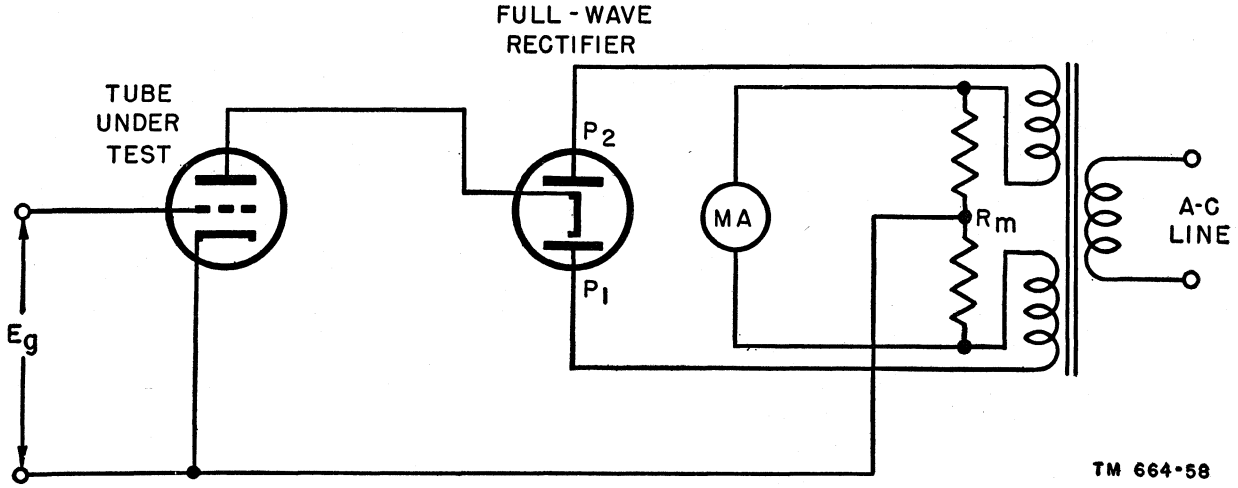


Figure 58. Schematic of dynamic mutual-conductance tester.

(5) When an alternating voltage is applied to the grid of the tube as well as to the fixed d-c bias, if the voltage swings positive at the same time that P_2 is positive, the plate current of the tube increases, and the plate-cathode resistance of the tube decreases. Because P_2 is positive and conducting, current flows through the upper half of R_m, and increases the deflecting force on the meter needle. When the a-c voltage applied to the grid swings negative, the grid of the tube under test becomes more negative, decreasing the tube current and increasing its resistance. Because of this, the current through the lower half of R_m decreases when P_1 is positive, and the deflecting force on the needle is decreased. With unbalanced currents in successive alternations, the meter reading becomes proportional to the difference in currents created by the a-c voltage applied to the grid which is obtained from another winding on the secondary of the input transformer; therefore, the meter indicates the change in plate current produced by a change in grid voltage.

(6) When converters are tested by the mutual-conductance method, the oscillator and mixer sections are tested separately. In checking the oscillator section, the alternating grid voltage is fed to the oscillator grid and the current is measured in the oscillator plate circuit. The mixer section is tested by feeding an alternating grid voltage to the signal grid of the tube and measur-

ing the current in the plate circuit. A much more important factor than the mutual conductance of the oscillator section is the conversion transconductance. This is the ratio of the change in i-f output current in microamperes to the corresponding change in alternating voltage on the r-f signal grid in volts. The mutual-conductance reading for the oscillator section of the converter when measured separately is from 2 to 10 times the normal conversion transconductance of the tube in micromhos.

d. OTHER TESTS. Other tests, such as the gas test, the noise test, and the short-circuit test, are used to detect particular defects in electron tubes.

(1) When gas is present in a vacuum-type electron tube, the electrons emitted by the cathode collide with the molecules of the gas, knocking one or more electrons out of these gas molecules. The result is positive gas ions, and the gas is said to be *ionized.* These positive gas ions move to the negatively biased grid of the tube and draw electrons from the grid circuit. The circuit used to check for the presence of gas is shown in figure 59. With switch S in position 1, plate current flows through the d-c meter. When the switch is thrown to position 2, if gas is present the current in the grid circuit will cause a voltage drop to appear across resistor R, resulting in an increase of plate current. Small current increases are normal; large plate-current increases indicate excessive gas.

(2) Noise in a receiver can be caused by loose electrodes, cathode-heater leakage, or nonuniform emission. If a tube has loose electrodes, moving the tube changes the spacing between electrodes, and changes the amount of emission. This effect is called microphonics and is indicated by a difference in the emission-test readings when the tube is rocked or tapped gently. A leakage path between the

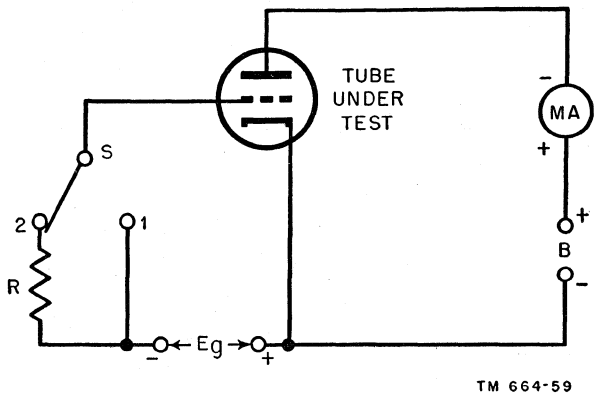


Figure 59. Circuit used to test electron tube for presence of excess gas.

cathode and the heater in an electron tube can be found with the circuit in figure 60. With switch S initially in position 1, pulsating dc flows through the meter and R, the plate-current limiting resistor. When the switch is thrown to position 2, no current should flow through the meter, since there is no complete circuit from plate cathode. If the meter does indicate a flow of plate current, there must be a leakage path between the cathode and the heater.

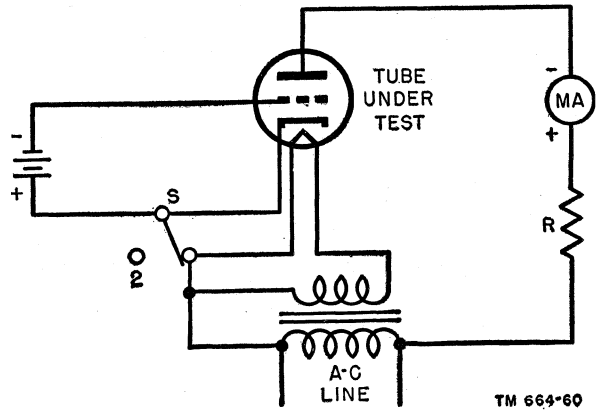


Figure 60. Circuit for testing electron tube for cathode-heater leakage.

(3) Short circuits between the electrodes of a tube can cause excessive current to flow in the plate circuit, tube noise, or intermittent operation of the tube.

A circuit for detecting short circuits in a tube is shown in figure 61. With the switch in position 2, the control grid is connected to the neon bulb side of the transformer secondary. All the other electrodes of the tube under test are connected through switches to the opposite side of the secondary. If the control grid is touching any of the other electrodes, a complete secondary circuit exists in the transformer secondary, and both plates of the neon bulb glow. If the control grid is not shorting out, only one plate of the neon tube glows, and then only during that half of the input a-c cycle when the grid is positive in respect to the cathode. Each of the other electrodes is tested for shorting in a similar manner. The element to be tested is connected to one side of the secondary, and all other electrodes are connected to the opposite side. Resistor R_1 limits the current through the neon bulb to a safe value and resistor R_2 bypasses any small alternating currents in the circuit caused by the stray capacitance of the wiring between other parts of the tester. This prevents stray currents from causing the neon tube to glow.

(4) Sometimes two electrodes in the tube do not touch at ordinary temperatures, but expand enough to cause a short circuit when heated. Therefore, the tube under test should be allowed to warm up to its normal operating temperature before making the test for shorts. Also, the tube should be tapped gently during the test because the electrodes may be loose and have a tendency to touch when the tube is vibrated. This circuit can be used also to test tubes for noise by connecting a pair of headphones or a loudspeaker in series with a .1-μf capacitor across the neon bulb. An intermittent short circuit, occurring too quickly to cause the neon bulb to glow, will cause an intermittent hum or crackle in the headset or speaker.

48. Typical Tube Tester

Most tube testers check either the cathode emission, or the mutual conductance; they also can check for short circuits, noise, and gas.

a. CIRCUITS.

(1) The filament supply for the tubes under test is taken from secondary A, shown in the diagram (fig. 62). The filament voltage selected by the switch depends on the tube under test. The remaining secondaries of the power transformer furnish the voltages applied to the other electrodes for the various types of tests.

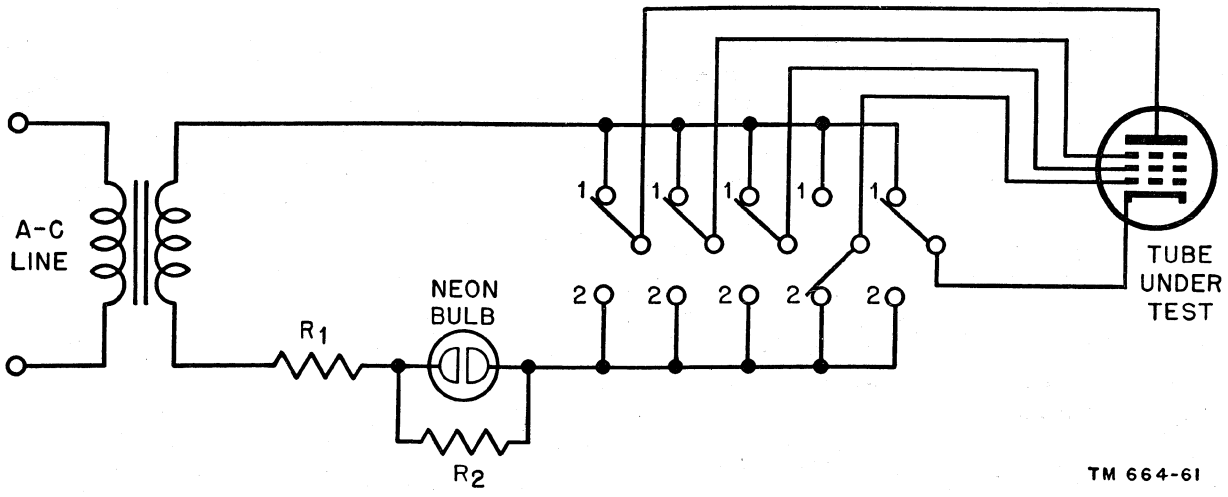


Figure 61. Circuit for testing electron tube for short circuits.

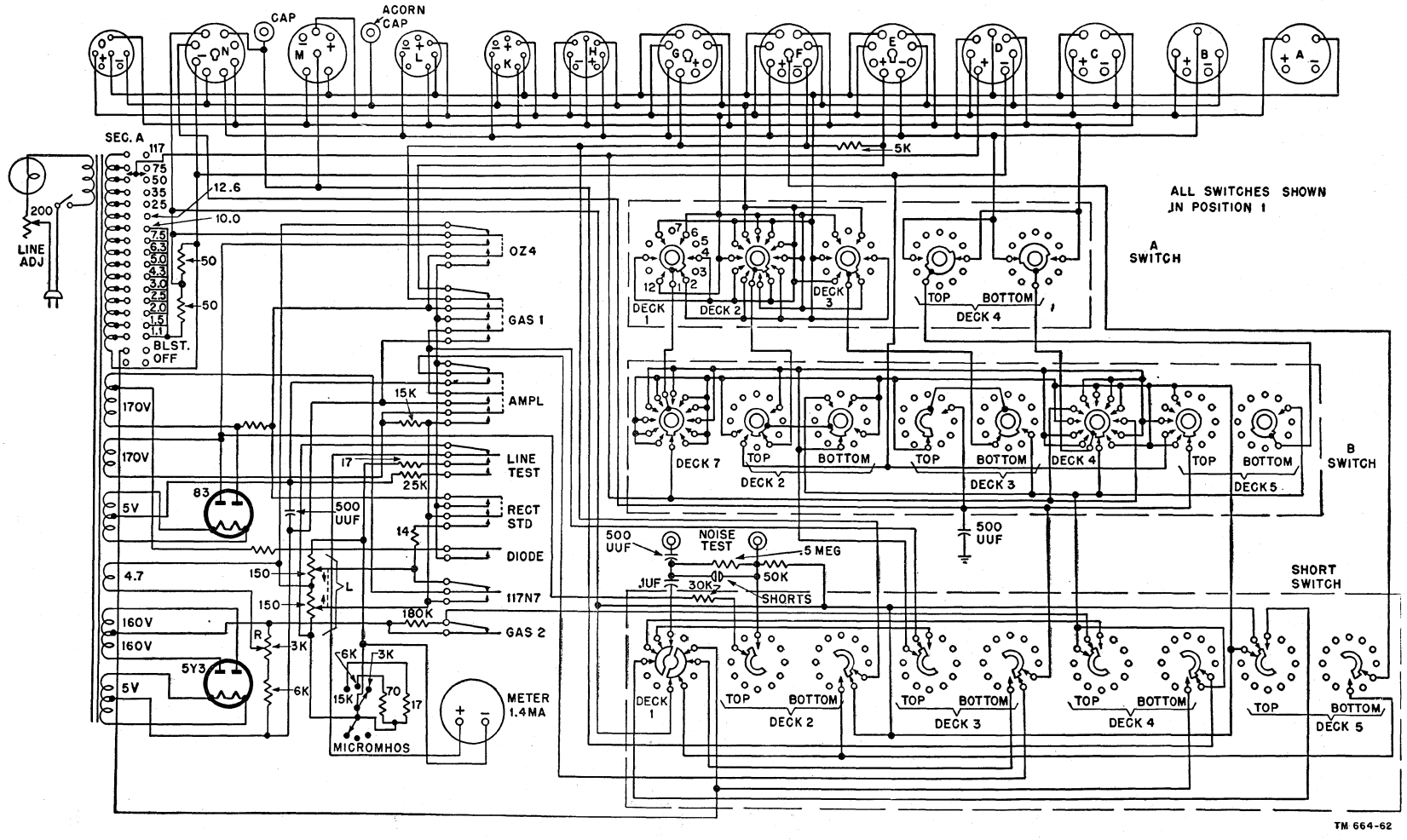


Figure 62. Schematic diagram of typical tube tester.

(2) The eight labeled push buttons shown in a line to the right of the transformer secondaries are used to switch in the various test circuits. Pushing the LINE TEST button connects the meter in series with the type 83 rectifier across a secondary winding of the transformer. The meter receives a d-c voltage proportional to the a-c voltage across the transformer primary. The LINE ADJ rheostat in the primary circuit is adjusted to obtain the proper voltage across the primary. The OZ4, RECT STD, and DIODE buttons apply the emission test circuit to the OZ4, to a standard full-wave rectifier, and to diode-type tubes, respectively. Each button furnishes a different value of a-c voltage to the electrodes of the tube under test. The GAS No. 1 and GAS No. 2 buttons are the two parts of the grid-circuit switch (fig. 59) for the gas test. The AMPL button applies the mutual-conductance test circuit to the electron tube tested. The push button labeled 117N7 is used with the RECT STD button to test the rectifier section of 117N7 tubes, which have special-type electrode connections.

(3) Potentiometer R, near the 197A rectifier tube, is used to adjust the negative bias on the grid of the tube under test to its operating value. Potentiometer L, the meter shunt, is adjusted so that the meter reads on the proper part of the scale for the tube tested.

(4) Switches A and B provide the proper tube-socket connections for the tube under test. The SHORT SWITCH, when used, connects various pairs of tube electrodes across the terminals of the test circuit for short circuits. A neon lamp indicates the shorts, and a pair of jacks is furnished for a noise test.

(5) The various electron-tube sockets which are mounted on the meter panel are shown across the top of the diagram. Each socket is used for a different type of tube base. The cap leads for tubes with caps are shown also.

(6) The switch shown next to the meter in the diagram is used to select one of three micromho scales for mutual-conductance measurements. It does this by changing the shunt resistance of the meter. The scale that is used depends on the mutual conductance of the tube under test. Figure 63 shows a front panel view of this tube tester. The settings of the various switches for each tube tested are given on the chart in the top of the case.

b. METER SCALES AND ROLL CHARTS.

(1) The tube tester described above used a chart for setting the switches and a meter calibrated in micromhos to show the condition of the tube. Another method used with an instrument similar to the one described above is shown in detail in figure 64. For mutual-conductance and emission tests, the qualitative scale shown in A is used. This is usually colored, the portion marked REPLACE being in red and the portion marked GOOD in green. If the needle swings over and stops in the green section, the tube under test is good (unless otherwise noted in the instructions for testing a particular tube). If the needle is over the red section of the scale, the tube is bad and should be replaced. If the needle indicates in the small portion between GOOD and BAD, labeled WEAK, the tube under test can be used for a few more hours but should be replaced soon. Good diodes cause the needle to read in the red section to the right of the DIODES mark. If the meter reads to the left of this mark, the diode must be replaced. The arrow in the center portion of the scale is used for the line-adjust test. Many tube testers have meters which include scales from which the mutual conductance of the tube under test can be read directly in micromhos. This is useful in determining whether a weak tube can be used in a circuit where low

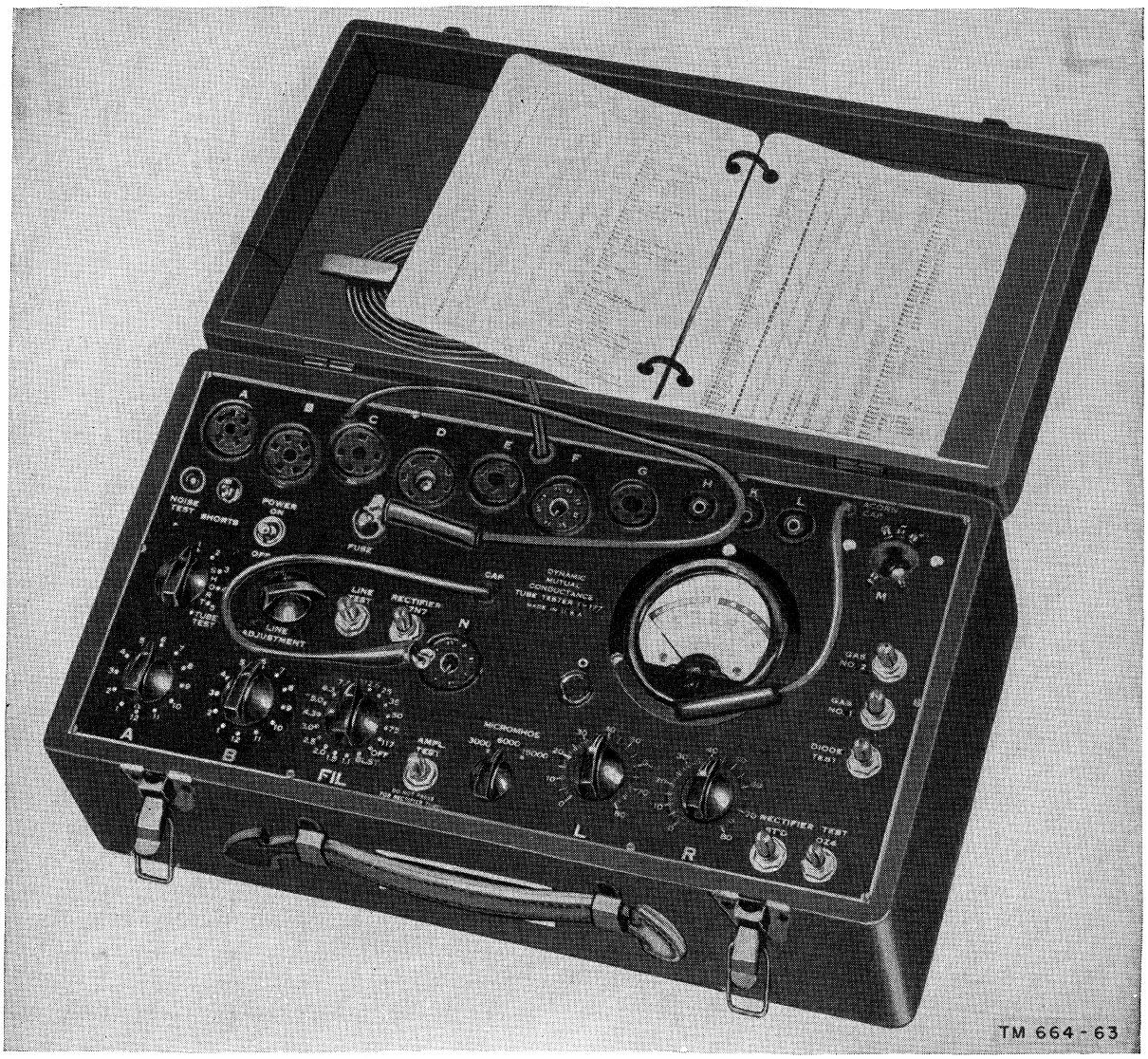
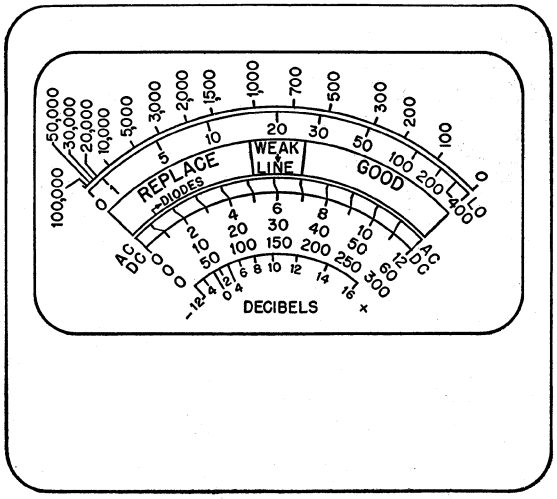


Figure 63. Instrument panel of typical tube tester.

amplification is permissible. The other scales shown in the figure are used with the multimeter section furnished with this particular instrument.

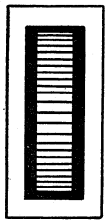
(2) In B, an enlargement of a roller-tube chart on an instrument panel is shown. Every tube that can be tested with this instrument is listed in numerical and alphabetical order on this chart. Under the columns headed A, B, C, D, E, and F are the settings to be used on these switches of the instrument when testing the tube whose name is in the same line as the settings. The hairline running across the window in front of the roller is used to pick out the tube under test. The knob to the right of the roller is turned until the tube number sits right on the hairline. The settings for the various switches fall on the same line. For example, the figure shows the roller adjusted to give the settings for the 6SK7 in the left window, and the 950 in the right. For the 6SK7, the settings on the A, B, C, D, E, and F switches are 3, 6, 16, 33, 5, and 1, respectively. The letters listed under the DEPRESS column refer to



A

TUBE	SECTION	A	B	C	D	E	F	DEPRESS
6SJ7		3	6	10	39	5	1	EF
6SK7		3	6	16	33	5	1	EF
6SL7	TRIODE 1	8	6	14	30	1	4	J
6SL7	TRIODE 2	3	6	14	30	1	4	D
6SN7	TRIODE 1	3	6	15	16	1	4	D

TUBE	SECTION	A	B	C	D	E	F	DEPRESS
884		7	6	0	2	11	1	BD
885		7	3	0	2	11	1	BC
950		3	2	29	20	1	1	BD
ACORN TUBE TEST DATA								



B

TM 664-64

Figure 64. Meter face and roll chart of typical tube tester showing settings for 6SK7 and 950 tube types.

the push buttons which must be depressed when making the mutual-conductance test for the particular tube. For the 6SK7, the buttons E and F are depressed to obtain the tube quality reading—GOOD, BAD, or WEAK.

(3) For multiunit tubes, each section is tested separately. The test for each section has its own switch and push-button settings. If a tube has two sections, a triode-diode, for example, the roller is set to the triode section for the tube type and the triode settings used, and then to the diode section and its settings used. Certain tube types are accompanied by notations, such as OK OVER ¼ SCALE. These notations signify that although the meter pointer falls within the red REPLACE sector, the tube is not to be rejected unless the pointer falls below the section of the scale noted.

(4) The data on the roll chart are compiled from tests made on thousands of tubes of the types listed. If a particular tube of a certain manufacturer consistently checks low on the GOOD sector of the scale, it may indicate that the manufacturer has changed the specifications of the tube. If this is so, new settings should be recorded for this tube so that the needle will read well up in the GOOD sector for a normally functioning tube. If an ordinary paper or card tube chart is furnished with the instrument used, the data are read from it in exactly the same manner as described for the roller chart.

c. USING TESTER.

(1) When using a tube tester, follow the instructions given in the equipment manual supplied. In general, the order of the tests made on a tube is:

(*a*) Test for shorts and filament continuity. This test is applied first to prevent damage to the meter if a short is present.

(*b*) Test for cathode-heater leakage.

(*c*) Test for audible noise.

(*d*) Test mutual conductance, if necessary.

(*e*) Test emission.

(2) Before inserting the tube in its socket or turning on the power, the various switch settings should be made. After the power is turned on, depress the line-adjustment button and rotate the line-adjust knob until the needle points to the proper setting on the meter, as given for the specific equipment. Then insert the tube to be tested into the proper socket and allow it to heat. Readjust the needle with the line-adjust knob so that it is again on the proper setting if it has drifted. Proceed to perform the tube tests in the order listed above.

49. Summary

a. A tube tester is an instrument which effects a number of different tests on an electron tube to indicate whether the tube is in proper operating condition.

b. Two methods of tube testing are used: The replacement method involves substituting a good tube for a suspected one, and the tube characteristics method uses a special circuit and a meter to measure certain characteristics (emission and mutual conductance) of the tube.

c. The important characteristics of a particular tube to be tested depend on its type. For diodes, cathode emission is important; for triodes and multigrid tubes, mutual conductance is important.

d. The most common defects in electron tubes are burned-out or open filament, loose and shorting electrodes, cathode-heater leakage, excessive gas in vacuum tubes, and nonuniform emission.

e. The replacement test for electron tubes tells whether a particular tube causes the circuit to be faulty. It does not tell how weak the tube is nor what is wrong with it.

f. The four most common tube tests effected by tube testers are: the emission test, the mutual-conductance test, the shorts test, and the test for excessive gas.

g. The emission of a tube is tested by connecting all the electrodes except the cathode and the heater to one side of the secondary of a power transformer, and the cathode in series with a milliammeter to the other side of the secondary. The current measured by the meter is an indication of the amount of emission.

h. Mutual conductance for a triode or a multigrid tube is the change in plate current caused by a change in grid voltage, divided by the change in grid voltage.

i. One method of finding the mutual conductance of a tube is to apply two different values of d-c voltage to the control grid of a tube under normal operating voltages, noting the change in plate current that results. This is called the static or grid-shift method.

j. The second method applies an alternating voltage to the grid in addition to its normal d-c bias. This approximates normal operating conditions for the tube with a signal voltage on its control grid. The shift in plate current as a result of the alternations in the grid circuit determines the amount of mutual-conductance.

k. Excess gas in a vacuum-type electron tube results in ionization and gas current in the grid circuit. This is measured by noticing the change in plate current caused by a change in the grid-circuit resistance.

l. Short circuits between the electrodes of an electron tube cause excessive currents, tube noise, and intermittent operation. To find a short circuit, all the electrodes except one (and the heater) are connected to one side of a power transformer secondary. The other electrodes are connected in series with a neon bulb to the other side of the secondary. If a short circuit exists, the neon bulb glows.

m. To test a tube for noise, a headset or radio receiver is connected across the neon bulb in the test circuit for short circuits. If the tube is noisy, a sound will be heard in the earphones or loudspeaker.

n. The typical tube tester includes most of the various types of tube-testing circuits. Push-button and rotary controls are used to supply

the tube under test with the proper voltages for the test circuit used.

o. Many different types of sockets are included with the tube tester. Each socket is used for a particular type of tube base.

p. The meter used with tube testers has an English-reading scale which reads GOOD, BAD, or WEAK (or similar notations), for the tube under test.

q. The settings to be made on each of the tube-tester switches for the particular tube under test are noted on either a roller chart or a conventional paper chart furnished with the tube tester.

50. Review Questions

a. What are the two basic methods of tube testing? Explain the principle of each method.

b. What are the defects most commonly found in faulty diodes? Triodes?

c. Draw a circuit which can be used to test the emission of a diode. Explain the operation of the circuit.

d. Define mutual conductance.

e. Draw a circuit for testing the mutual conductance of a pentode by the static method.

f. Explain the dynamic method for testing the mutual conductance of a triode. Draw a circuit to effect this test.

g. What characteristic of a converter tube resembles the mutual conductance of an amplifier tube? How is the approximate value of this characteristic obtained?

h. Draw a gas-test circuit and explain its operation.

i. How are short-circuited electrodes in a triode detected? Draw the circuit.

j. What basic controls are necessary on the panel of any typical tube tester?

k. What is the first test applied to a suspected tube with a tube tester? Why?

SECTION VIII
POWER MEASUREMENT

51. Introduction to Power Measurements

a. GENERAL. Power in an electrical circuit is the rate at which energy is used, and the unit of measurement is the watt. A comparison shows that it takes 746 watts of electrical energy to do the same amount of work as 1 horsepower of mechanical energy. Power measurements in electronics include measurements of the power an electrical device takes from the line, the power input and output of a transmitter, and the power output of a receiver.

b. POWER FORMULAS.

(1) In a resistive circuit, the power in watts is equal to the voltage across the resistor in volts multiplied by the current in amperes, or

$$P = E \times I.$$

For example, the power expended in a resistor when the voltage across it is 110 volts and the current through it is .5 ampere is:

$P = E \times I = 110 \times .5 = 55$ watts.

(2) Since, by Ohm's law, $I = E/R$, other forms of the power equation are:

$$P = \frac{E^2}{R}$$

and

$$P = I^2R.$$

(3) These formulas apply to purely resistive a-c and d-c circuits. In some a-c circuits, however, the current is not in phase with the voltage. This phase difference must be taken into account, and a true power consumption in such circuits is found by using the formula

$P = E \times I \times$ power factor.

Power factor is equal to the cosine of the phase angle by which the current is out of phase with the voltage.

(4) A-c power output usually is measured across a resistor. This prevents any complication caused by power factor, since current and voltage always are in phase in a resistive circuit. If any two of the three quantities-voltage, current, and resistance—are measured, the power then can be calculated by using the appropriate formula.

52. Electrodynamometer

The electrodynamometer or wattmeter generally is used to measure power taken from the line for operation of any piece of electrical equipment.

a. CONSTRUCTION. The dynamometer consists of two stationary coils and one moving coil. The stationary coils have many turns of small wire with high resistance. The movable coil has a few turns of large wire with low resistance and is pivoted in jewelled bearings. The meter needle is attached to one end of the movable-coil shaft and the damping arrangement, similar to that of the moving-vane meter, is attached to the other end. Springs are provided to control the needle swing.

b. THEORY OF OPERATION.

(1) The high-resistance stationary coils are connected across the source of voltage and the movable coil is connected in series with the load (A, fig. 65). The current through the load passes through the movable coil and a magnetic field builds up around it. The current through the voltage coil depends on the voltage across the load and the magnetic field set up by the two coils causes the movable coil to be repelled. The repulsion is directly proportional to the voltage across the load and also to the current passing

through the load. Consequently, the meter pointer registers according to the power consumption, or $E \times I$. Dynamometers or wattmeters can be used with either dc or line-frequency ac.

(2) The movable coil must have low resistance and low inductance in order not to disturb the circuit in which it is connected. The inductance of the fixed voltage coil must be low, so that the current through the coil is in phase with the voltage across it.

(3) Since both the current and the voltage coils have resistance, a power loss takes place in the wattmeter. A typical wattmeter has a power loss of 2 watts in the potential coil and less than 1 watt in the current coil. This loss usually is specified on the instrument for full-scale deflection.

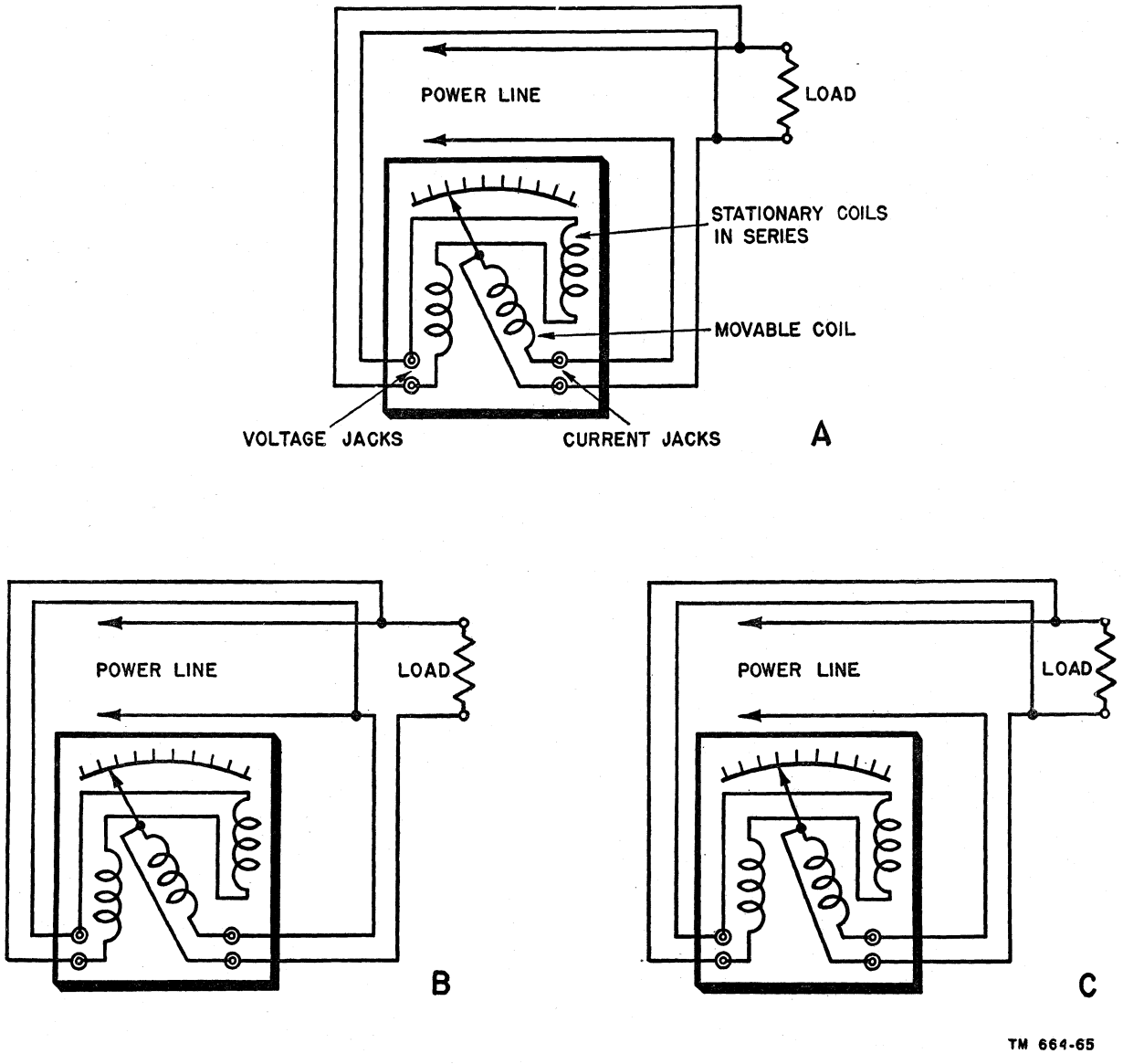


Figure 65. A. Wattmeter connection for measuring input power.
B. Alternate wattmeter connection.
C. With load disconnected, uncompensated wattmeter measures own power loss.

(4) There are two possible connections, as shown in figure 65. In A, the current through the potential coil also goes through the current coil. The current coil, therefore, is measuring both the load current and the potential coil current. In B, the potential coil is measuring the voltage of the load added to the voltage across the current coil. Both measurements involve some error.

(5) Some wattmeters are compensated so that the power loss caused by wattmeter connections is corrected for in the design of the instrument. Otherwise, for exact measurements, the specified power consumed by the wattmeter should be subtracted from the final wattmeter reading. The meter power loss can be checked by disconnecting the load, and leaving the wattmeter connected as in C. With the load disconnected, the potential coil is in series with the current coil and the uncompensated meter reads its own power loss; this is the correction factor which should be subtracted from the reading with the load connected. If the wattmeter is compensated, the reading is 0.

c. RATINGS. Both the voltage and current coils have definite ratings and overload of either can damage the meter. For example, one type of meter may be designed to measure a maximum of 200 watts, and this should not be exceeded. The current coil has a maximum rating of 3 amperes, and the potential coil a maximum rating of 130 volts.

d. DYNAMOMETER SCALE. In dynamometers or wattmeters, deflection is linear and practically uniform over the full range of the wattmeter. Double the power gives double the deflection. Because the voltage and current coils are *separately* connected, power is doubled when current through *either* the voltage or the current coil doubles. When current through both coils doubles, there is four times the power, and also four times the deflection.

e. ACCURACY. The accuracy of dynamometers is high, usually within 1 percent.

f. A-C POWER MEASUREMENTS. In a-c circuits when current and voltage are not in phase, power is found by

$$P = E \times I \times \text{power factor.}$$

Dynamometer wattmeters automatically take into account the power factor of the circuit. The wattmeter always reads true power, no matter how much lag or lead there is in the current flow. When current lags or leads, less power always is consumed than when the same current is in phase with the voltage. When current is out of phase, the power factor is less than one. With out-of-phase currents through the current coil, maximum current never occurs at the same instant as maximum voltage in the voltage coil. When lines of forces are maximum in one coil, they are less than maximum in the other coil. The result is that the movable coil does not deflect as much as it does when the current and voltage are in phase. Wattmeters, therefore, measure true power regardless of current lag or lead.

53. Radio Transmitter Output Power Measurement

a. THERMOCOUPLE AMMETERS. In radio transmitters, thermocouple ammeters generally are used for measuring the r-f current. The meter is connected in series with the antenna circuit to measure the r-f current, and the current indicated is used to calculate the power output. To find the power output, the square of the current is multiplied by the known resistance of the antenna:

$$P = I^2R.$$

Thermocouple meters consist of a combination of a thermocouple and a d-c moving-coil meter movement.

b. THERMOELECTRICITY. A thermocouple consists of two dissimilar metals joined at one end. If the junction of these metals is heated, a d-c voltage is produced at the free terminals. This voltage is proportional to the heat difference between the hot and the cold ends. This phenomenon is called *thermoelectricity.*

c. CONSTRUCTION AND OPERATION. The thermocouple meter consists of a heater through which the r-f current flows, a thermocouple attached to the heater element, and a d-c moving-coil meter movement connected to the free ends of the thermocouple. The d-c voltage at the free ends of the thermocouple causes direct current to flow through the meter, which is cali-

brated in terms of r-f current. The heater is made of platinum or nickel alloy and is usually in direct contact with the junction of the thermocouple. The thermocouple itself is made of constantan and platinum alloy. The external circuit and the thermocouple meter circuit are entirely separate.

d. COMPENSATED THERMOCOUPLE.

(1) The generated voltage depends on the temperature difference between the hot (junction) and the cold (free) ends. This temperature difference should be caused only by the current being measured and should not be influenced by atmospheric temperature. To eliminate atmospheric influences, the free ends of the thermocouple should be attached to the center of separate copper strips so that they will be constantly at the average temperature of the ends (not the center) of the heater element. The ends of the copper strips are placed close enough to the heater ends to have the same temperature, but are electrically insulated from them by means of thin mica sheets (fig. 66). When current flows, the temperature at the *center* of the heater element becomes much greater than the temperature at the heater ends or at the free ends of the thermocouple. For a given current, the temperature difference between the thermocouple junction and the free ends is constant, regardless of the ambient (surrounding) temperature.

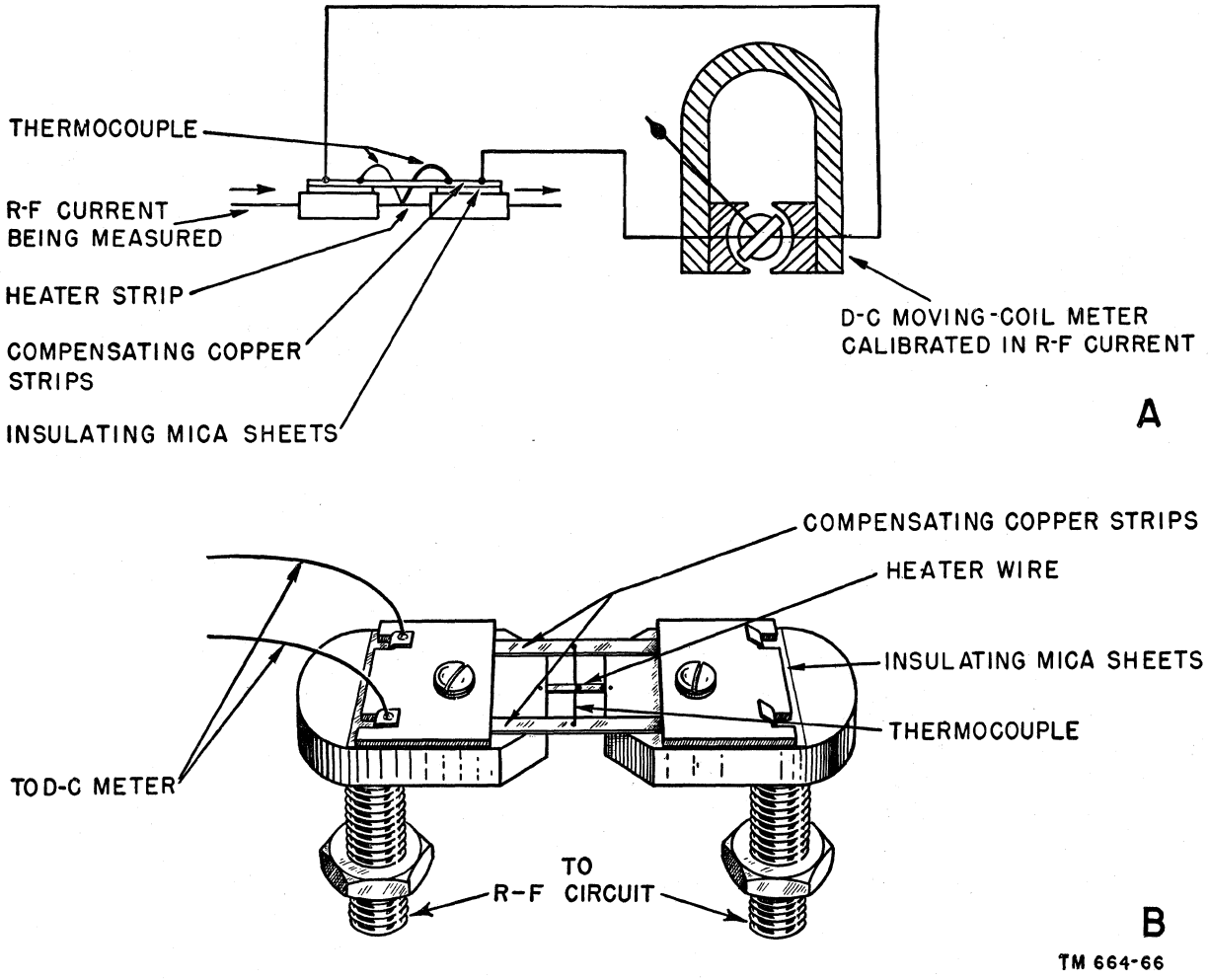


Figure 66. Compensated thermocouple r-f ammeter.

(2) Compensated heater elements are placed within the meter in instruments measuring from 15 to 20 amperes. Higher range heaters have the same construction, but the heating element is external to the meter because of the amount of heat developed. Heater wire designed to carry from .5 ampere to 3 amperes is solid. Above 3 amperes, the wire is tubular.

e. MOUNTING. When the combined heater element and thermocouple are located in the antenna circuit and the meter mounted some distance away, the high-frequency currents in the antenna circuit are not affected. The d-c voltage generated at the thermocouple is fed to the connecting cable going to the meter, and to avoid r-f currents in the meter circuit, r-f chokes and bypass capacitors are inserted (fig. 67) when the meter is some distance from the thermocouple unit. The specific resistance of the connecting line must be accounted for when the meter is calibrated.

g. SCALE. Deflection is proportional to the amount of heat in the heater wire and this, in turn, is proportional to the square of the current passing through it. The thermocouple ammeter, therefore, has a square-law scale. Since the bottom of a square-law scale is crowded, readings in that area are inaccurate. Thermal meters are so selected that the expected value of current is at least half of the full-scale range. For example, if the estimated current is 7 amperes, the meter range should not exceed 10 amperes. Special pole pieces may be used in the meter to produce deflection that is more uniform over the range.

h. MEASURING RADIO TRANSMITTER POWER OUTPUT.

(1) With the power switch turned off and the antenna disconnected, a dummy antenna is connected in the antenna output circuit (fig. 68). The dummy antenna has a specified impedance and should have the same general electrical characteristics as the real antenna, except that it does not radiate energy. Its impedance should be the same as that of the one specified in the instruction manual covering the particular transmitter being tested. A thermocouple ammeter then is connected in series with the dummy antenna.

(2) The transmitter is turned on and properly tuned according to the instruction manual. The reading of the r-f ammeter is noted, and output power is calculated. Since the current in the antenna circuit is given by the

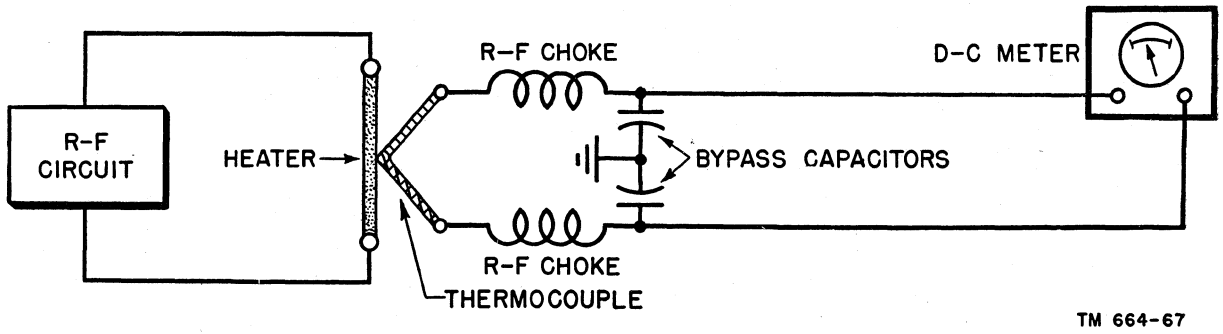


Figure 67. R-f chokes and bypass capacitors added to thermocouple ammeter circuit to prevent r-f from entering d-c meter circuit.

f. FREQUENCY RESPONSE. Thermocouple ammeters are calibrated for specific frequencies since a frequency increase causes *skin effect*—that is, the tendency of an r-f current to travel at the surface of the wire. This effectively increases the resistance of the heater wire. Meter deflection, therefore, changes with frequency, although the amount of current does not change. Heaters made of short sections of very thin wall tubing reduce the amount of error caused by skin effect. Where thermocouple meters are required to operate over a considerable frequency range, correction data charts are provided by the manufacturers.

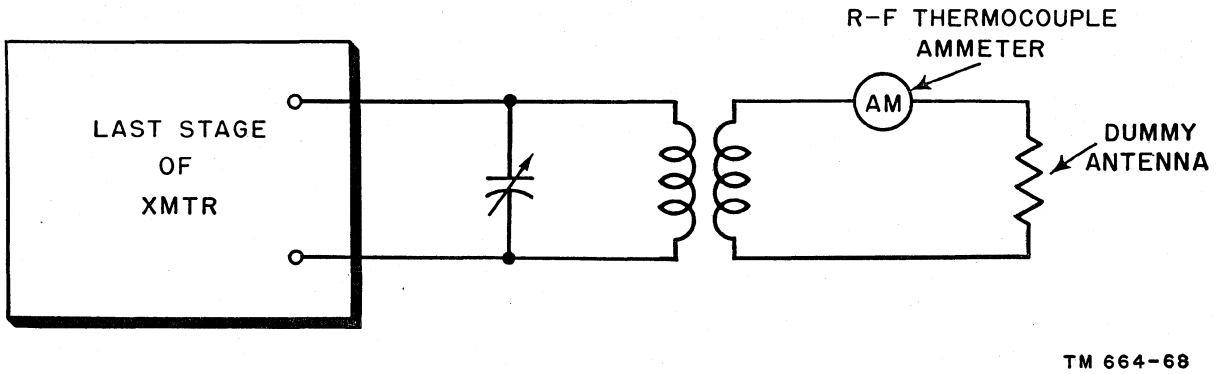


Figure 68. Measuring power output of radio transmitters.

ammeter and the load is known, power is found by:

$$P = I^2R.$$

This figure then is compared to the rated figure for the transmitter under test.

54. Uhf (Ultrahigh-Frequency) Transmitter Output Power Measurement

a. BASIC CONSIDERATIONS.

(1) In d-c and low-frequency a-c circuits, electrons flow through the wires of the circuit and electromagnetic and electrostatic fields appear around the wire. As the frequency increases, the current tends to travel along the surface of the wire rather than through the center. The lines of force rising from and collapsing into the center of the wire have a greater density than those at the surface. The inductance of the wire, therefore, can be considered greater at the center than at the surface. This concentrates the electrons near the surface of the wire and causes them to travel along the surface.

(2) In radio transmitters, r-f current flows in the antenna wire. The radiated signal, however, is not considered a current flow through space, but rather a projection of electromagnetic and electrostatic lines of force through space.

(3) In transmitters operating in the ultrahigh-frequency range from 300 to 3,000 mc (megacycles), the r-f energy from the transmitter is coupled to the antenna by means of rectangular or round hollow pipes called *waveguides*. R-f energy in the form of electromagnetic and electrostatic lines of force goes through these pipes from transmitter to antenna, and the signal inside these waveguides resembles the radiated signal more than it does current flow through a wire.

(4) To measure power output in these transmitters without upsetting operation, a different type of power-indicating instrument is necessary. The device generally used is a *thermistor-bridge* wattmeter.

b. THERMISTOR.

(1) A thermistor is a specially constructed resistor which has a *negative temperature coefficient*. This means that its resistance decreases as its temperature rises and increases as its temperature falls.

(2) Factors that can cause a change in thermistor temperature are temperature changes around the thermistor, a-c or d-c currents flowing through it, and r-f energy striking it.

(3) Thermistors are constructed from a mixture of metallic oxides. Nickel oxide usually is the base, with manganese, uranium, or copper oxide plus other materials, for binders.

c. BASIC BRIDGE OPERATION.

(1) A bridge is a sensitive device for measuring resistance, inductance, or

capacitance by indicating a voltage balance (ch. 11).

(2) A in figure 69, R_1 and R_2, having equal resistance, are connected in series across a 6-volt battery. The voltage drop across each resistor is the same and point X is 3 volts positive in respect to the negative terminal of the battery. A second branch of resistors, consisting of R_3 and R_4 in series, now is placed in parallel with R_1 and R_2, as in B. R_3 and R_4 are equal in value; therefore, the voltage drops across them are equal, and point Y is 3 volts positive in respect to the negative terminal of the battery. If a voltmeter is connected from point X to point Y, as in C, it will read 0, since both points are at the same potential. Also, when a galvanometer is placed between X and Y, as in D, since the difference of potential between the two points again is 0, there is no current flow through the meter, and the reading is 0.

(3) If the resistance of R_1 is decreased, and the values of the other resistors remain the same, the voltage drop across R_1 decreases. The voltage drop across R_2, therefore, must be greater, and point X *less* than 3 volts positive in respect to the negative terminal of the battery. Point Y is still 3 volts positive, since there has been no change in the R_3-R_4 branch of the circuit. Point X is now negative compared to point Y, and there is a current flow from X to Y through the galvanometer. The more the resistance of R_1 decreases, the more negative point X becomes in respect to point Y, and the greater the current flow through the galvanometer.

d. OPERATION OF BASIC THERMISTOR BRIDGE. The thermistor bridge circuit (fig. 70) closely follows the pattern of the basic bridge described above. In place of R_1, a small bead thermistor designated TH_1 is used and a variable resistor, R_5, is placed in series with the

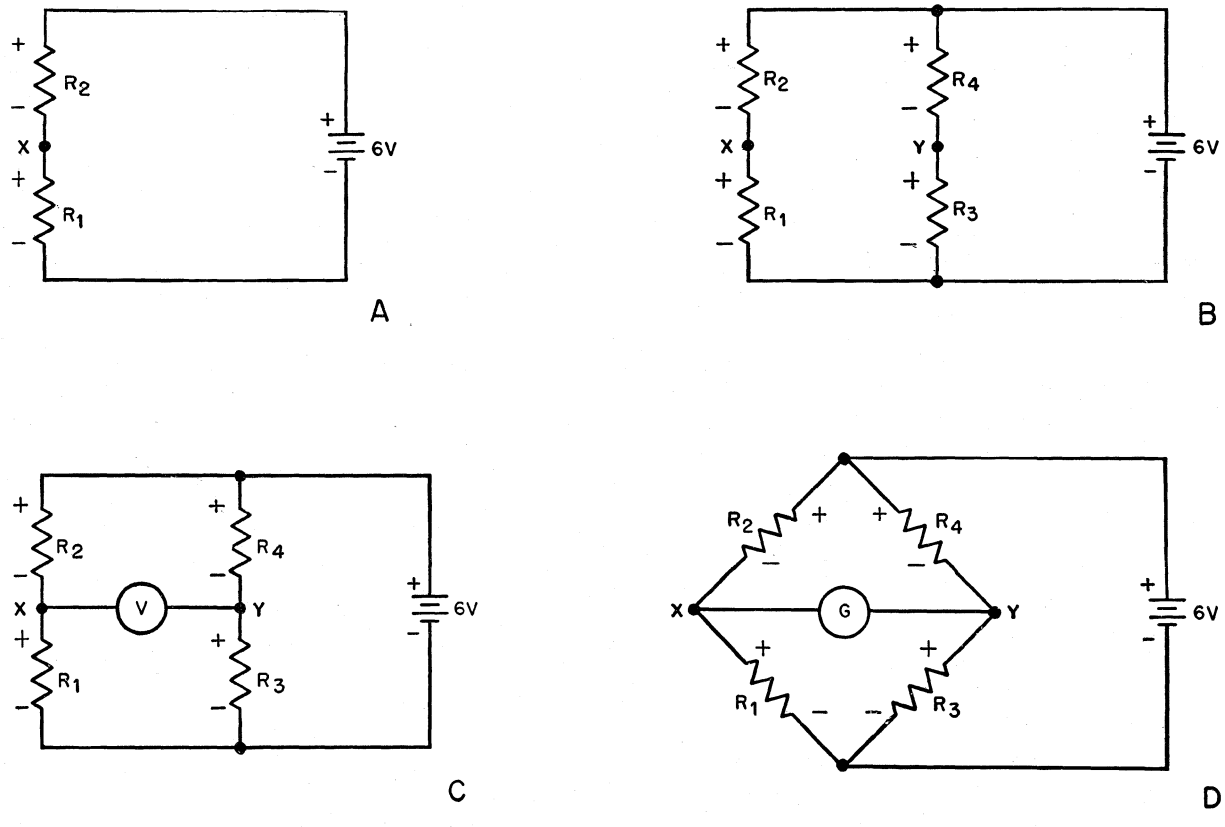


Figure 69. Basic bridge operation.

entire bridge circuit. R_2, R_3, and R_4 are 250 ohms each and R_5, which is variable from 0 to 125 ohms, is called the *balancing control.* Resistor R_5 varies the current flowing through the circuit. This controls the initial current flowing through the thermistor, TH_1. R_5 is varied until there is enough current flow through TH_1 to make its resistance 250 ohms. When all resistors including the thermistor are 250 ohms, the galvanometer reads 0. The bridge is now said to be balanced and is ready for making power measurements.

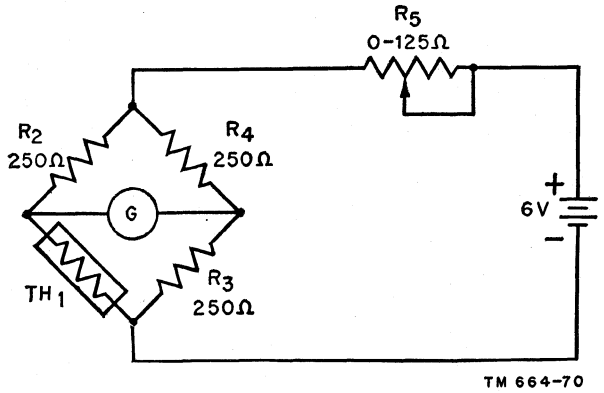


Figure 70. Basic thermistor bridge circuit.

e. THERMISTOR BRIDGE POWER MEASUREMENT. A thermistor bridge unit is connected to a uhf transmitter according to the instructions in the manual covering the particular equipment. A known portion of the r-f energy is fed to the thermistor bridge wattmeter, striking the thermistor bead. The resistance of the thermistor decreases in proportion to the r-f energy absorbed, and the meter reads accordingly. From this reading, the power output of the transmitter is calculated and compared to the rated power output of the transmitter to determine whether there is maximum output.

f. METER MOVEMENT USED. Thermistor bridge wattmeters are d'Arsonval meter movements. The meter movement is usually 0 to 200 microamperes, and to obtain maximum sensitivity it is used without series or shunt resistors.

g. COMPENSATED BRIDGE. The simple thermistor bridge described above has some advantages. Since thermistors change value as the temperature changes, and since the different temperatures cause the sensitivity of the bridge to change, the simple bridge requires frequent zero settings. Additional thermistors and compensating networks are added to balance out these effects.

55. Radio Receiver Output Power Measurement

a. Receiver power output is measured to determine whether the receiver is operating at maximum efficiency. By using a signal generator to inject a carefully measured value of signal voltage to the antenna terminals, and measuring the power output across a resistor connected to the output (loudspeaker) terminals, the efficiency of the receiver is determined.

b. A simple way to check audio power output is to use an a-c voltmeter across a known value of resistance. This value of resistance is specified in the instruction manual covering the particular receiver. The resistor is connected to the receiver output according to the instructions and an a-c voltmeter is placed across the resistor. With a signal generator delivering an input voltage at the receiver antenna, the voltmeter reads the output voltage across the resistor. Power output then is computed by using the formula $P = E^2/R$.

c. Receivers also are rated according to their *sensitivity.* Sensitivity is the value of signal voltage at the antenna that will give a specified power output—usually 1 milliwatt (.001 watt)—at the receiver output terminals. For example, a given receiver has a sensitivity rating of 5 microvolts. This means that a 5- microvolt signal at the antenna results in a power output of 1 milliwatt across the output resistor with normal receiver operation. The object of power-output and sensitivity checks is to determine whether the receiver is performing with its rated sensitivity.

d. Meters used to check receiver power output include copper-oxide rectifier type a-c meters, vtvm's, and db (decibel) meters.

56. Output Power Measurement

a. DECIBEL NOTATION. In the early period of telephone development, it was necessary for engineers to solve the problem of transmitting audio power over long distances of telephone

wire. They needed some unit which *expressed the comparison of output power to input power* in the transmission lines, the amplifiers, and every other stage of transmission. The unit selected was the *bel,* named in honor of the inventor of the telephone. Since the bel is a large unit, it is more convenient to use a smaller one, the *decibel,* which is one-tenth of a bel. It is possible to express power output in decibels as well as in watts, and many a-c voltmeters are calibrated in decibels. Instruction manuals commonly express power output in db's.

b. DEFINITION OF LOGARITHM. A logarithm is the power to which a number is raised or the number of times it is to be used as a factor. For example, 5^2 means that 5 is to be raised to the second power, or that 5 is to be used as a factor twice, or 5 times 5. In this case, 2 is the exponent or logarithm. Any number can be expressed as an exponent or logarithm of a base number. Also, any number other than 1 may be used as a base number. In the example above, the exponent 2 is the logarithm of 5^2 in reference to the base number 5. Although any number other than 1 may be used as a base number, the most commonly used is 10. The logarithm of 100 using the base 10 is 2, since 10^2 is equal to 100 and 10 must be raised to the second power in order to obtain the number 100. It is possible to express any number as an exponent or logarithm of the base 10. If the number is between 1 and 10, then the exponent or logarithm will be expressed as a fraction or decimal between 0 and 1 because any number to the 0 power is equal to 1, and 10 to the first power is equal to 10. The logarithm of 6 to the base 10 is .7782, since it must be a fraction or decimal between 0 and 1; therefore, the exponent must also equal .7782 and 6 is expressed in exponential form as $10^{.7782}$. Similarly, the logarithm of 582 must fall between 2 and 3, since the number 582 is between 100, the second power of 10, and 1,000, the third power of 10. The logarithm of 582 is 2.7649 and the exponential form is $10^{2.7649}$. Mathematical and radio textbooks have tables showing the logarithm of any number to the base 10.

c. BEL AND DECIBEL FORMULAS. The unit selected with which to compare any two values of power is the bel. If the larger value of power to be compared is designated as P_2 and the smaller value as P_1, then

$$bels = \log \frac{P_2}{P_1}.$$

Since this unit is too large for general use, it is more convenient to use a smaller one, the decibel, which is equal to one-tenth of a bel, or

$$db = 10 \log \frac{P_2}{P_1}.$$

Both of these units are relative measurements and do not specify any definite amount of power. They are the logarithmic ratio between any two values of power.

d. APPLICATION OF DB FORMULA. There are two general ways of applying the formula given above:

(1) Power input can be compared to power output, and the result expressed in db's. In using the db formula, the larger power always is used for P_2 and the smaller for P_1. Depending on which is the input, and db figure represents either gain or loss.

(2) Any power input or output can be compared to a standard reference level and this method generally is the one used. The standard zero reference level used in military installation is 1 milliwatt. Any other quantity of power is compared to this reference level, and the ratio is expressed as dbm (decibels referred to 1 milliwatt).

(3) For example, an amplifier has an output of 10 watts. What is the output expressed in db?

$$db = 10 \log (P2/.001) = 10 \log (10/.001)$$
$$= 10 \log 10{,}000.$$

The log of 10,000 is 4 ($10{,}000 = 10^4$), and

$$db = 10 \times 4 = 40.$$

The answer is 40 dbm gain, or +40 dbm. This does not mean that the input to the amplifier is necessarily 1 milliwatt. It simply means that the output of the amplifier is 40 dbm above 1 milliwatt. *One milliwatt represents only a convenient, standard reference level.*

e. TYPES OF DB METERS.

(1) The db meter is a copper-oxide rectifier-type a-c voltmeter, or a-c vtvm, calibrated in db's. Usually, the db

ohms each and R_5, which is variable from 0 to 125 ohms, is called the *balancing control.* Resistor R_5 varies the current flowing through the circuit. This [illegible] temperatures cause the sensitivity of the bridge to change, the simple bridge requires frequent zero settings. Additional thermistors and compensating networks are added to the

meter is part of a multimeter and the same jacks or switch positions used for a-c voltage measurements are used for db measurements (fig. 71). A db meter actually measures a-c voltage and a db scale is included on the face of the meter so that the reading can be made in db's rather than a-c volts.

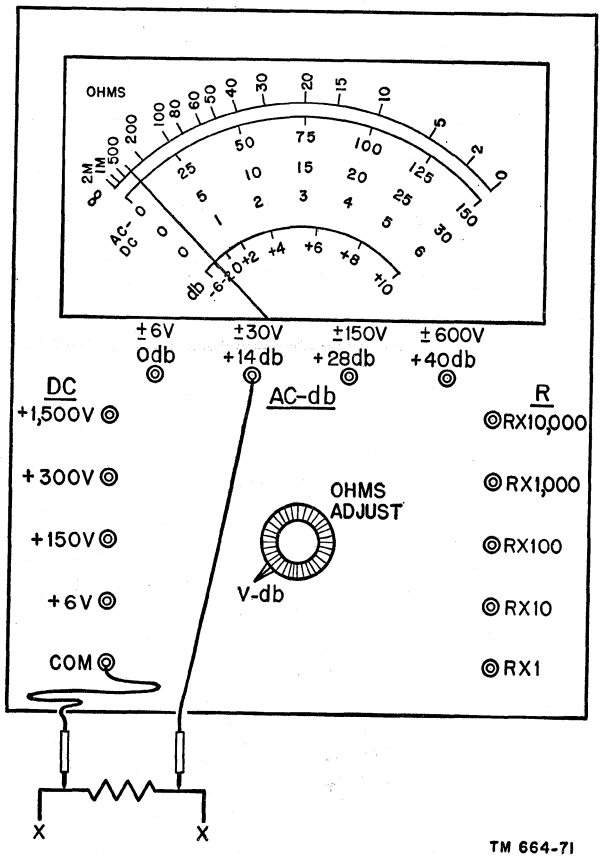


Figure 71. Typical multimeter incorporating a db meter.

(2) When marking off the db scale on the meter face a reference point is selected, based on a specified value of wattage and voltage which represent 0 db and a specified value of resistance across which measurements are to be made. Power varies as the square of the voltage, and when the voltage is measured across a fixed value of resistance P is equal to E^2/R.

(3) In many commercial meters, 0 db is 6 milliwatts, or 1.73 volts across a 500-ohm resistor.

$P = E^2/R = (1.73)^2/500 = .006$ watt, or 6 milliwatts.

Based on this reference point, various voltage readings are made on the 6-volt a-c scale (fig. 71) across a 500-ohm resistor, and the resulting deflection marked off in decibels. It is possible also to compute the value in db's of any deflection by use of the voltage db formula. For example, measuring 5.46 volts on the 6-volt a-c scale results in almost full-scale deflection. In marking off this voltage on the db scale, the db voltage formula is used to determine the equipment db reading:

$db = 20\ log\ (E1/E2) = 20\ log\ (5.46/1.73)$
$= 20\ log\ (3.16) = 20\ (.5)$
$= 10.$

Therefore, this point on the scale represents 10 db and the entire scale is marked out in db's in the same way. A voltage of 1.73 volts across a 500-ohm resistor represents 0 db, and deflections less than 1.73 volts represent negative db readings. When the load resistor is other than 500 ohms, the db setting will not be at 1.73 volts, and other readings on the scale will not be the same. For example, if the 0-db point is to be 6 milliwatts across a 600-ohm resistor, the 0-db setting on the meter will be at 1.9 volts rather than a 1.73 volts, and the 10-db setting will be at 6 volts rather than at 5.46 volts. Therefore, the load resistance as well as the zero reference level must be known if accurate readings are to be obtained.

f. MEASURING HIGHER DB RANGES.

(1) To aid in the understanding of the theory of reading db meters on higher ranges, a review of a-c voltmeters is offered. Higher voltage ranges are obtained by adding more multiplier resistance in series with the meter movement. In going from the 6-volt range to the 30-volt range, the full-scale reading is 30 volts rather than 6 volts, and a separate set of numbers for each range is included on the face of

the meter. However, even if no separate set of numbers is provided, it is not difficult to read the meter when the test lead is in the 30-volt jack.

(2) Assume that the numerals 0 to 6 volts are on the face of the meter. On the 30-volt scale, it is necessary only to multiply each reading by 5. Multiplying 6 volts by 5 gives 30 volts, which represents full-scale deflection on the 30-volt range. On the 150-volt range, it is necessary to multiply the reading by 25, since 6 volts multiplied by 25 results in the required 150-volt full-scale deflection.

(3) In multipurpose meters, it is customary to have one set of numbers marked off on the db scale. Therefore, in reading power ratios higher than those indicated on the lowest a-c voltage range, it is necessary to use a higher a-c voltage range and algebraically add the correct factor to the reading.

(4) When taking db readings on a higher range, the correct algebraic-addition factor must be used. For example, in figure 71, the 30-volt a-c range also is marked +14 db and this sum is added algebraically to the meter reading to get the actual db value. When a reading is taken on the +14 db range and the meter reads —2 db on the 0 db scale, the actual db value is —2 added to +14 or +12 db. Any voltage reading on the 30-volt range is 5 times larger than any reading on the 6-volt range. Since there is only one db scale, the increase in db's when using the next higher scale must be the difference in db's between 30 volts and 6 volts. This is found by the db voltage formula,

$$db = 20\ log\ (E1/E2) = 20\ log\ (30/6) = 20\ (log\ 5) = 20 \times .7$$

$$db = 14.$$

Therefore, 30 volts is +14 db compared to 6 volts. Since any reading on the 30-volt range is 5 times larger than an equal deflection on the 6-volt range, it is necessary to add +14 db to a reading when using the 30-volt range. In the same way, the 150-volt range is marked +28 db. This means that +28 db must be added to any db reading when using this range, and so on.

g. DB POWER-OUTPUT METER.

(1) The db meters described have a definite drawback since the db calibration on the meter face is based on readings taken across a specified value of resistance. If readings are taken across any other value of resistance, it is necessary either to add a correction factor, usually supplied by the meter manufacturer in table form, or to compute the correct db value.

(2) The db meter (fig. 72) eliminates this drawback by giving direct readings across any value of resistor from 2.5 ohms to 20,000 ohms without requiring a correction factor. It is an a-c rectifier voltmeter, calibrated both in db's and milliwatts. In accordance with Signal Corps specifications, the zero-reference level represents 1 milliwatt, or .775 volt, across 600 ohms. The db readings on this meter are with reference to this level and are called dbm's.

(3) The power output of an a-f amplifier, or any other audio equipment, is measured across a specified value of load resistor which is placed across the output terminals of the equipment. To simplify measurements, this meter contains different values of load resistance that are automatically connected across the output terminals of the equipment when the meter is placed across them. The value of load resistance can be varied from 2.5 to 20,000 ohms by means of the impedance control knob. The meter can read a power range from .1 milliwatt to 5 watts, and a db range from —10 db to +37 db.

h. OPERATION.

(1) The same amount of voltage across different values of load resistance gives different power readings on the face of the meter. For example, 10

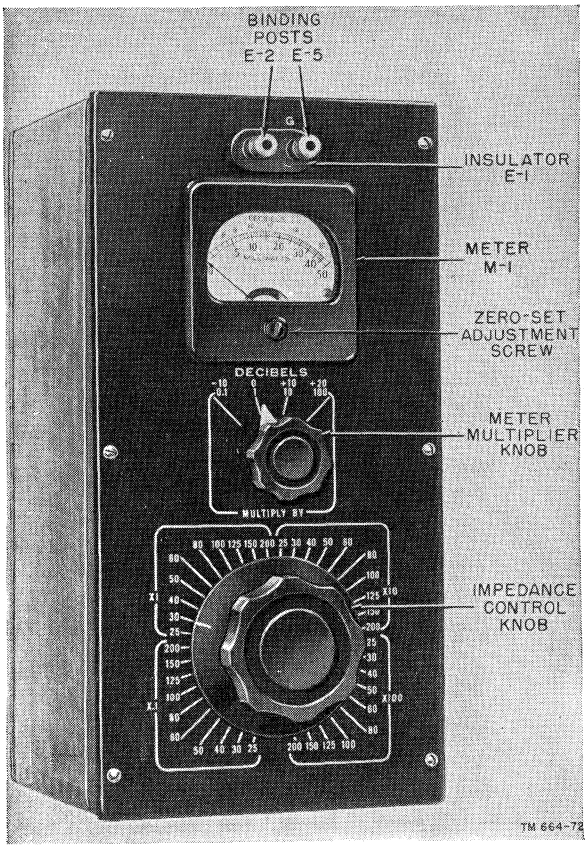


Figure 72. Photograph of db power-output meter.

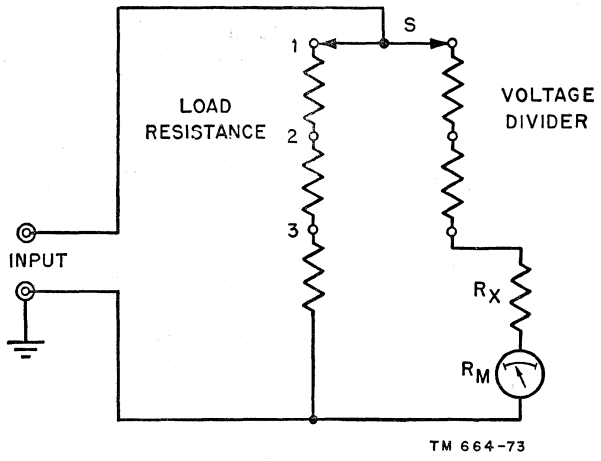


Figure 73. Simplified schematic of db output-meter set-up for measuring power across high load R.

volts across 100 ohms results in a power dissipation of 1 watt and the same amount of voltage across 200 ohms represents only .5 watt. The smaller the load resistance, the greater the power when the voltage remains the same.

(2) The meter circuit must be designed so that the readings of the meter depend not only on voltage but also on the load resistance, since power depends on both voltage and resistance. This is accomplished in the meter circuit by placing the applied voltage across two parallel paths: the load resistor, and a voltage divider which includes the meter (fig. 73). When 10 volts placed across the entire load resistance on the left, and the switch is in position 1, the 10 volts is divided between the voltage divider, the meter, and the multiplier resistance. Only part of the 10 volts is across the meter circuit, and the meter reads this portion of the voltage. When the switch is in position 2 or 3, the same amount of voltage is across a smaller load resistance, more power is dissipated in the meter, and the meter reads higher.

(3) The complete schematic for this meter is shown in figure 74. Switch S_1, going to the load resistor and the voltage divider, has 40 positions and includes not only resistors but also an autotransformer. The autotransformer is in the circuit whenever S_2 reduces the load resistance to 300 ohms or less, and increases the voltage applied to the meter. In this way, higher power outputs are indicated for lower values of load resistance. The autotransformer is connected in the circuit and the resistance of the voltage divider is cut out by means of switch S_2. This switch is ganged to S_1.

(4) Because transformer voltage varies with frequency, R_1 and C_1 are placed in the circuit to form a low-frequency compensating network in parallel with the autotransformer. At higher frequencies, the output voltage of the autotransformer tends to be high, but the reactance of C_1 is low. At the lower frequencies, the voltage across the autotransformer falls off, but the reactance of C_1 is higher. The net re-

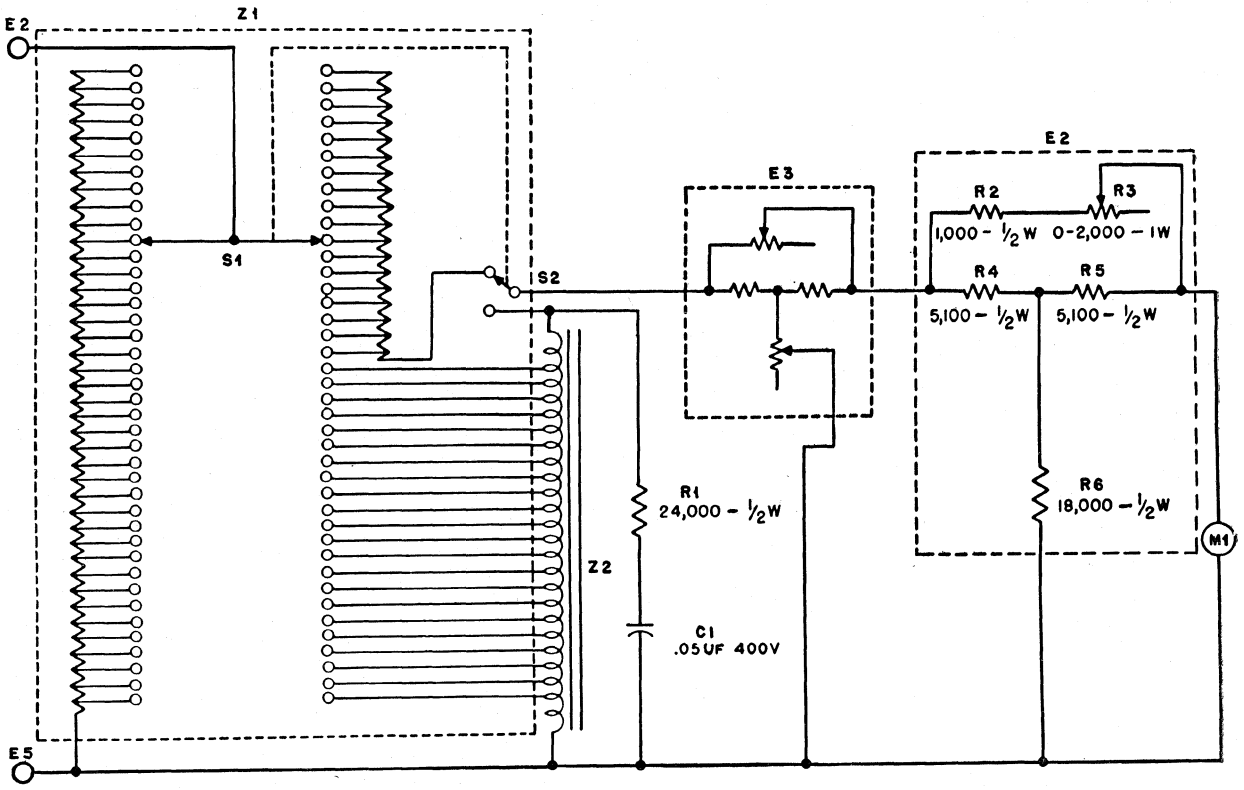


Figure 74. Schematic of output meter.

sult is to provide about the same output from the autotransformer at all frequencies.

(5) The multiplier resistance in series with the meter is a network of resistors that can be varied in four steps, and is controlled by the *meter multiplier* knob. The E_2 network controls the amount of voltage fed to the meter by the voltage divider and is used for calibrating the meter.

i. MEASURING RECEIVER POWER OUTPUT. To measure the power output of a receiver, a signal generator is connected to the input terminals of the receiver by means of a dummy antenna. A carefully measured amount of modulated r-f signal voltage from the generator is fed to the input of the receiver, and a db meter is connected to the output terminals of the receiver. With the impedance control knob of the db meter set to the output impedance of the receiver, the db meter is read to find the power output. Instruction manuals usually specify the number of db that should be read at the receiver output with a given signal input.

j. SETTING IMPEDANCE CONTROL KNOB. The *impedance control* knob (fig. 72) must be set to the value of output impedance of the equipment being measured. For example, if the value of impedance is 600 ohms, the impedance control knob is turned to 60 in the $\times$ *10* section (60 times 10 = 600). If the impedance is not known, the meter is connected in the usual manner and the impedance control knob turned until the highest output is secured. Maximum power output is obtained from any equipment when the output impedance matches the impedance of the equipment. If the meter does not give a maximum reading when the impedance control knob is rotated, the impedance of the equipment under test is beyond the range of the impedance network. The meter readings in such a case are not reliable and should be considered only as approximate values.

k. READING METER SCALE. The *meter multiplier* knob is set to give a reading as close to

midscale as possible since at that point the calibration is read easily and accurately. When measuring *power output* in milliwatts, the milliwatt reading is multiplied by the setting of this knob. For example, the pointer reads 12 milliwatts and the meter multiplier knob is at 10. The actual value is 12 times 10, or 120 milliwatts. When measuring *db's*, the db reading is added algebraically to the db setting of the multiplier knob. For example, if the meter reads 13 on the db scale and the meter multiplier is set at +10 db, the actual reading is 10 plus 13, or +23 db.

l. VU METER. The vu meter is used in audio equipment to indicate the input power to a transmitter or transmission line. It is a copper-oxide rectifier-type a-c voltmeter with a standardized speed of pointer movement, speed of return, and calibation. The vu meter pointer has a rapid rise and slow fall, making it easy to follow audio peaks and modulation envelope values. The meter is marked to indicate percentage of modulation.

m. USING VOLTMETER. The vu meter usually is placed in the input of audio equipment and gives an indication of volume level as so many vu above or below a zero reference level of 1 milliwatt. It also indicates the amount of power-providing peaks that will modulate a transmitter 100 percent.

n. READING VU METER. The actual vu level is the algebraic addition of the meter reading and the switch setting, just as with db meters. For example, if the meter reads +1 vu and the switch is set at +8 vu, the output is +9 vu.

o. VU METER AND DB METER. The meter gives correct vu readings across only a 600-ohm load, and 0 vu is indicated when .775 volt is applied across a 600-ohm load. This is a power level of .001 watt. A change of 1 vu is equal to a change of 1 db. Therefore, any number of vu's equals the same number of db's. When 0 db means that 1 milliwatt is being delivered to 600 ohms, then db's and vu's are identical. A vu meter always can be used as a db meter, but a db meter can be used as a vu meter only when there are steady audio outputs. When the audio level is varying, the db meter and the vu meter read different instantaneous values.

57. Summary

a. Power is the rate at which energy is used.

b. Input power to electrical devices usually is measured with a dynamometer, or wattmeter.

c. Power output of transmitters usually is measured with a thermocouple meter or a thermistor-bridge wattmeter.

d. Power output of receivers usually is measured with an a-c voltmeter or db meter.

e. Audio modulation power input to transmitters or transmission lines can be measured by means of db meters or vu meters.

f. A dynamometer or wattmeter consists of high-resistance stationary coils, connected across the load or voltage source, and a low-resistance movable coil and pointer connected in series with the load. The meter reads true power in a-c or d-c circuits.

g. A thermocouple ammeter consists of a heater element, a thermocouple, and a d-c moving-coil meter movement.

h. Compensated thermocouples eliminate effects of ambient temperature by having the free ends of the thermocouple attached to copper strips.

i. A thermocouple and heater unit can be placed in the antenna circuit, and the meter can be mounted some distance away.

j. A thermistor is a negative temperature coefficient resistor. Its resistance changes when the temperature around the thermistor changes, when a-c or d-c currents flow through it, or when r-f power is absorbed.

k. Thermistor-bridge wattmeters are used to measure power output of some ultrahigh-frequency transmitters.

l. Receivers are rated according to *sensitivity*, or the signal input which gives a specified power at the receiver terminals.

m. Decibel meters can be used to check power output of receivers and audio-modulating power input to transmitters.

n. Db meters are calibrated on the basis of being used across a specified load.

o. A vu meter is a copper-oxide rectifier-type a-c voltmeter with standardized calibration and speed-of-pointer movement.

p. The vu meter was developed to eliminate the variations found in db meters.

58. Review Questions

a. Define power.

b. List the most common types of power measurements and the instruments used.

c. What are the three formulas for electrical power in resistive circuits?

d. Explain the construction and operation of a dynamometer.

e. How can wattmeters be connected? Show by means of diagrams.

f. How can the power loss in uncompensated wattmeters be checked?

g. Explain the construction and operation of a thermocouple ammeter.

h. Describe the purpose and construction of a compensated thermocouple.

i. How are thermocouple ammeters used to measure the output power of radio transmitters?

j. What is a thermistor?

k. Describe the electrical construction and operation of the basic thermistor-bridge circuit.

l. Explain how receiver sensitivity measurements can be performed.

m. Define the decibel.

n. How are db meters used?

o. What is a vu meter? How is it read?

p. Compare vu meters to db meters.

SECTION IX

SIGNAL GENERATORS AND OSCILLATORS

59. Signal Generator

A signal generator is an instrument which generates an a-c signal suitable for test purposes. Actually, it is a miniature radio transmitter and can be made to generate signals for any desired frequency.

a. USES. These generated signals can be modulated or unmodulated and are used for:

(1) *Receiver alinement*: Adjusting the i-f (intermediate frequency) and r-f tuned circuits to their correct frequencies.

(2) *Receiver performance testing*: Checking receiver sensitivity and a-f (audio-frequency) response, selectivity, and signal-to-noise ratio.

(3) *Receiver servicing*: Trouble shooting a defective receiver. The defective stage often is found by *signal substitution* or *signal tracing.*

b. TYPES.

(1) When signal generators are classified according to *frequency,* they can be either a-f or r-f generators. A-f generators usually are called *audio oscillators.* They are capable of producing signals in the audio range from 20 to 20,000 cps. R-f generators generate signals over any specified range of frequencies above 20,000 cps, but no single generator will cover all of the r-f ranges used in radio and radar. Different r-f generators are available, each covering a specified frequency range, and many of these also have an audio output available. The audio output can be variable over part or all of the audio range, or can be a fixed frequency, usually 400 cps.

(2) The classification of r-f and a-f signal generators also can be subdivided according to their signal output. Audio oscillators can have either a sine-wave or a square-wave output. R-f signal generators can have either pure r-f, a-m (amplitude-modulated), f-m (frequency-modulated) or pulse-modulated output. In a-m generators, an audio signal is mixed with the radio frequency and the r-f *amplitude* varies with the amplitude of the audio signal. In f-m generators, the radio frequency is varied in *frequency* at a rate determined by the amplitude of the audio signal. In pulse modulation no audio signal as such is mixed with the radio frequency, which is interrupted, however, usually at an audio rate, a number of times per second.

60. Principles of Tuned Circuit

All signal generators have an *oscillator* stage and, therefore, a review of oscillator fundamentals is offered before a discussion of typical signal generators.

a. TUNING FORK AS RESONANT CIRCUIT.

(1) Musicians sometimes use a tuning fork (fig. 75) to obtain a sound of a certain frequency. When this is struck, it vibrates against the air molecules, displacing the air around it at a frequency determined by its size. The waves of air strike the eardrums of the listener, causing them to vibrate at the same frequency, and produce the sensation of sound.

(2) The energy that has been imparted to the fork by the force of the original blow is used up gradually in moving

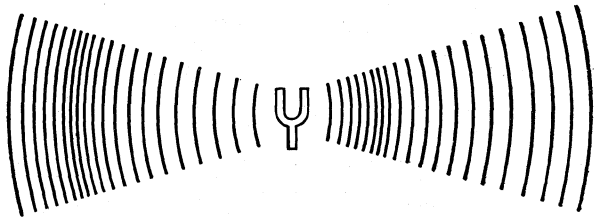


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Figure 75. Tuning fork produces signal when struck, by vibrating at its resonant frequency.

the branches of the fork back and forth. The gradual decrease of vibrations after tuning fork is struck is called *damping*.

b. ELECTRICAL RESONANCE.

(1) Electrical circuits also will produce vibrations if given an *electrical* tap, producing signals at a frequency depending on their physical characteristics. This is the resonant frequency of the circuit (A, fig. 76).

(2) The inductor and capacitor act electrically as a tuning fork does mechanically. A tuning fork, when tapped, starts vibrating mechanically. An electrical tap applied to the coil and capacitor sets them vibrating electrically. The electrical tap can be supplied by connecting the circuit across a battery with a switch in series, as in B. When the switch is closed for an instant, and then opened, an electrical vibration or a-c signal is produced for a time.

(3) The coil and capacitor together comprise a circuit which is resonant at a frequency determined by the values of L and C, L being the inductance of the coil and C the capacitance of the capacitor. When the circuit is excited, it vibrates, or oscillates, at a frequency equal to $1/2\pi\sqrt{LC}$.

c. FACTORS GOVERNING FREQUENCY AND DAMPING.

(1) If the capacitance is large, it accumulates a large charge when the switch is closed and takes a *long time* to discharge. Therefore, the frequency of oscillation is comparatively low. If the capacitance is small, it accumulates a smaller charge and the capacitor discharges *faster*. Therefore, the frequency of oscillation is higher. When the coil has a large inductance, the capacitor takes more time to discharge through the coil, because of the greater opposition to current flow. The greater the value of either L or C, the lower the frequency will be; the smaller are L and C, the higher the frequency.

(2) The more resistance in the coil, the more the oscillations are damped, and the faster they fall to zero. When the coil has a low resistance, less damping takes place, and the oscillations continue for a longer time before they die out.

61. Basic Oscillator Operation

a. DEVELOPMENT OF OSCILLATOR CIRCUIT. It is possible to produce undamped or continuous oscillations in the tuned circuit (B, fig. 76) if

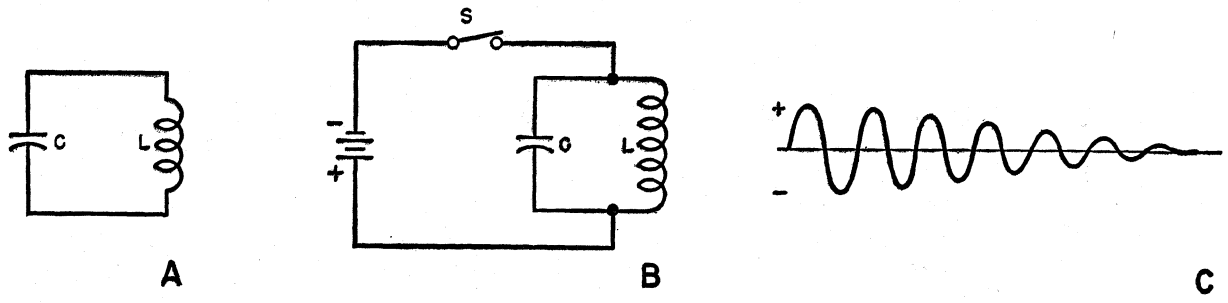

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Figure 76. Electrical resonance.

the battery switch is opened and closed rapidly every cycle, or even every other cycle. This gives the tuned circuit an electrical tap at the right instant, sustains the oscillations, and prevents them from damping out. An oscillator using an amplifier tube provides a regular tap (feedback) for the tuned circuit and generates a continuous, undamped a-c voltage at a frequency determined by the inductance and capacitance of the tuned circuit.

b. TYPICAL SELF-EXCITED OSCILLATOR OPERATION.

(1) Figure 77 shows a *self-excited* oscillator circuit, so-named because it requires no external signal to start or maintain oscillations. Because the tuned circuit is in the grid of the tube, it is called a *tuned-grid* oscillator. When the switch is turned on, current starts to flow in the plate circuit of the tube and passes through the primary of transformer T_1. Current through the primary causes magnetic lines of force to cut across the secondary, inducing a voltage in it.

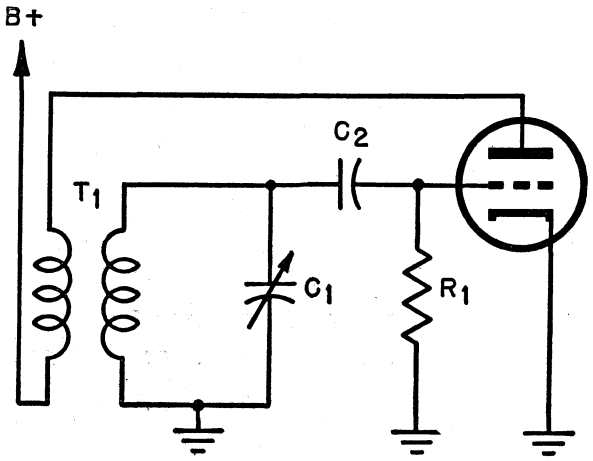


Figure 77. Tuned-grid oscillator.

(2) When the voltage induced in the secondary is positive in respect to ground, grid current flows and starts to charge the tuning capacitor C_1. The grid of the tube is positive in respect to the cathode, and the plate current increases. Because more plate current flows through the primary of T_1, the tickler coil, more lines of force are cutting across the secondary. This induces a larger voltage in the secondary and increases the current through the tube until it reaches the point of saturation. Saturation occurs when the current flow to the plate is maximum and no further increase in plate current can result.

(3) When the tube reaches saturation, the plate current neither increases nor decreases, and the lines of force around the tickler coil become stationary. Since no lines of force cut across the secondary, no voltage is induced, and the charged tuning capacitor starts to discharge through the coil.

(4) As the voltage across the tuning capacitor decreases, the voltage of the grid becomes negative in respect to the cathode. When the voltage on the control grid becomes sufficiently negative, current through the tube is cut off and no current flows in the plate circuit. The tuning capacitor discharges, and the voltage across the capacitor drops to zero. The lines of force surrounding the secondary of T_1 collapse and cause the polarity across the secondary to become negative in respect to ground. This voltage increases, and the tube remains cut off during the entire negative half-cycle of oscillation in the tuned circuit.

(5) The tuned circuit voltage then goes to maximum negative, back to zero, and starts to go to positive. As the tuned circuit voltage becomes more positive, it bucks the discharge of C_2 through R_1, and the voltage across R_1 decreases.

(6) There comes a point when the voltage between the grid and cathode decreases so that it is not enough to keep the tube cut off. The tube starts to conduct. The primary (tickler) feeds back a voltage to the secondary. The secondary, which is already a generator because it was charging the capacitor, gets a further boost or kick from

the lines of force of the tickler coil. The tuning capacitor is, therefore, charged a little more than it otherwise would be. The sequence then repeats itself, generating oscillations at a frequency determined by L and C.

62. Crystal Oscillator

a. CRYSTALS AND PIEZOELECTRICITY. A crystal such as quartz, tourmaline, or Rochelle salts has the property known as *piezoelectricity.* Piezoelectricity is the generation of a voltage when the crystal is placed under mechanical strain such as compression or expansion. The reverse of this also is true, since a crystal will expand or compress when a voltage is placed across it. For example, when a Rochelle salts crystal is used in a phonograph pick-up, the slight variation in the record grooves causes the crystal to vibrate and generate a small amount of voltage. This voltage is then fed to an audio amplifier, and reproduced through the speaker. When a voltage is applied to a quartz crystal in a transmitter, it vibrates at a frequency determined by the thickness of the crystal and the manner in which it is cut.

b. QUARTZ CRYSTAL PROPERTIES. Quartz crystals are not affected by light shocks or moisture and are very hard. They have low internal friction when vibrating, and since there is very little damping they make excellent oscillators. The natural frequency of vibration depends on the thickness of the crystal which is placed between two metal plates and allowed some freedom to vibrate.

c. CRYSTAL CIRCUIT. A of figure 78 shows a typical crystal oscillator circuit with feedback accomplished through the grid-to-plate capacitance of the tube. Electrically, the crystal is the equivalent of an L-C tuned circuit in a tuned-plate tuned-grid oscillator (B of fig. 78).

d. OPERATION. When the switch is turned on, current starts to flow in the plate circuit of the tube. A small amount of voltage from the output is fed back to the crystal in the grid circuit through the interelectrode capacity of the tube, C_{gp}, and causes it to compress or expand. The crystal then springs back to its normal position and in so doing generates a voltage. This voltage controls the flow of current through the tube and acts to reinforce the oscillations in the plate circuit. The tuned-plate circuit continues to feed a voltage to the grid, and the action continues. The tuned-plate circuit and the crystal each acts to keep the oscillations of the other going.

e. ADVANTAGES AND DISADVANTAGES OF CRYSTAL OSCILLATOR. Crystal oscillators are stable in operation, since their frequency deviation is small. They also can be used to supply harmonics for frequency-multiplying circuits. However, the frequency of a crystal oscillator

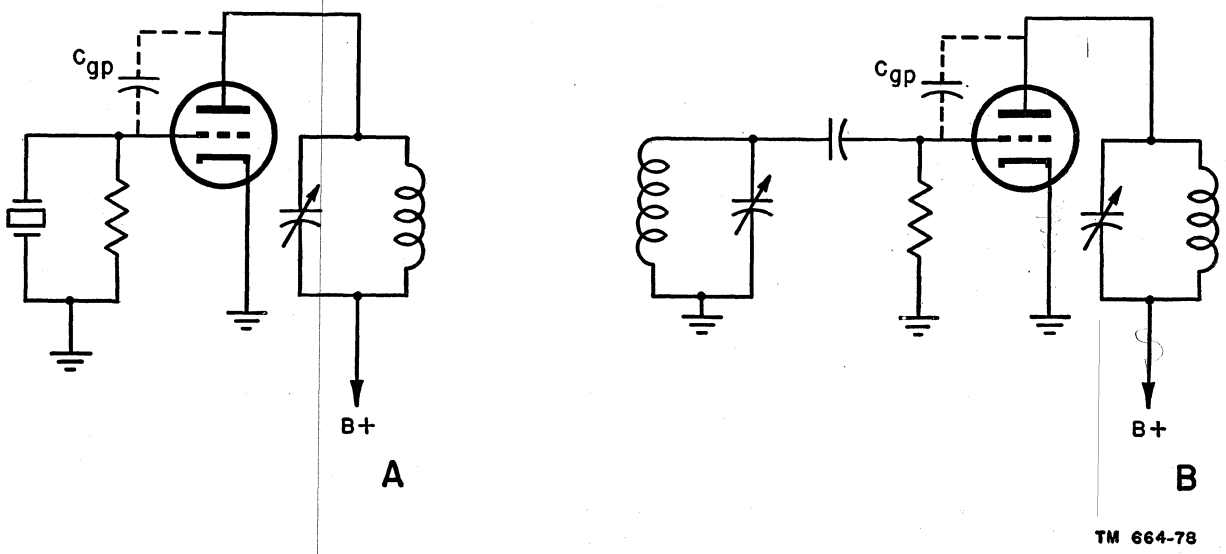


Figure 78. Crystal oscillator circuit and electrical equivalent.

is not variable and, to change frequency, a different crystal must be used. When their rated current is exceeded, the amplitude of vibration may become so great that the crystal will crack.

63. Audio Oscillator

a. SINE-WAVE AUDIO OSCILLATOR. The range of hearing is, approximately, from 16 to 16,000 cps, depending on the individual. Sine-wave audio oscillators generate signals above and below this range and are useful in checking audio-amplifier circuits for operation, voltage, gain, and frequency response.

b. CHECKING A-F AMPLIFIER FREQUENCY RESPONSE. Theoretically, audio-frequency amplifiers should amplify the entire audio-frequency range equally. In most audio amplifiers, however, the low and the high frequencies are not amplified as much as the middle frequencies; in military application, this response sometimes is deliberately limited. To test an audio amplifier for frequency responses, a sine-wave audio oscillation can be used. A constant value of signal is applied to the input of the amplifier and the output of several frequencies throughout the entire range is measured at the amplifier output with an a-c voltmeter or an oscilloscope (B of fig. 79). The result of these measurements can be shown in a chart called a *frequency-response curve.*

c. SQUARE-WAVE GENERATORS.

(1) The square-wave generator is used for a quick check of the frequency response of an audio-frequency or video-frequency amplifier. Since square waves are rich in harmonics, a poor

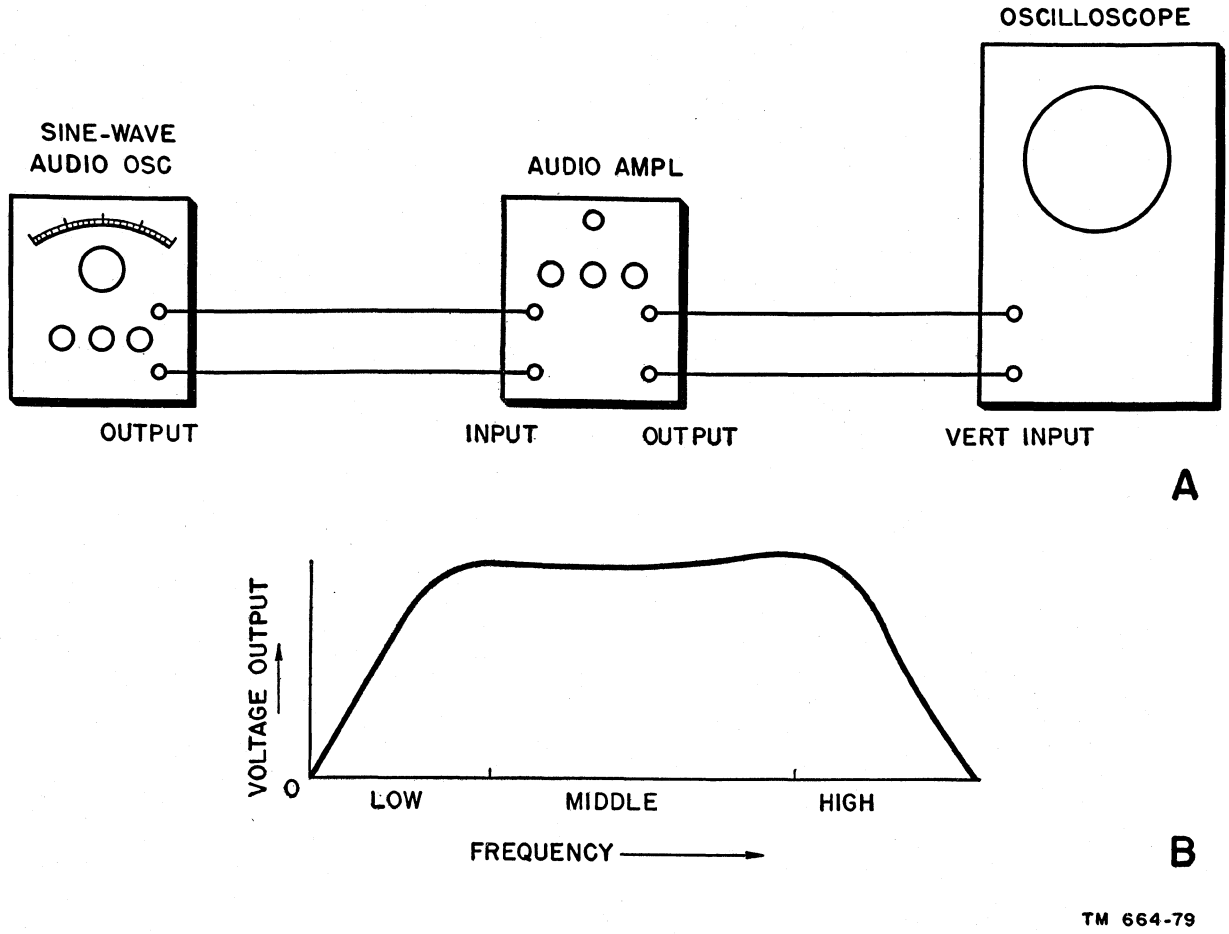


Figure 79. A. Using sine-wave audio oscillator and oscilliscope to check frequency response of audio amplifier. B. Amplitude of output plotted against audio frequency.

frequency response will distort the square wave, and the amount of distortion can be seen easily on the scope. One method of producing square waves is to generate sine waves in an oscillator in the usual way. The sine waves then are fed to an amplifier which is driven to plate saturation on the positive half-cycle of the input signal and to cut-off on the negative half-cycle. This causes the peaks of the sine wave to be cut off at the top and bottom, and produces a square wave (fig. 80).

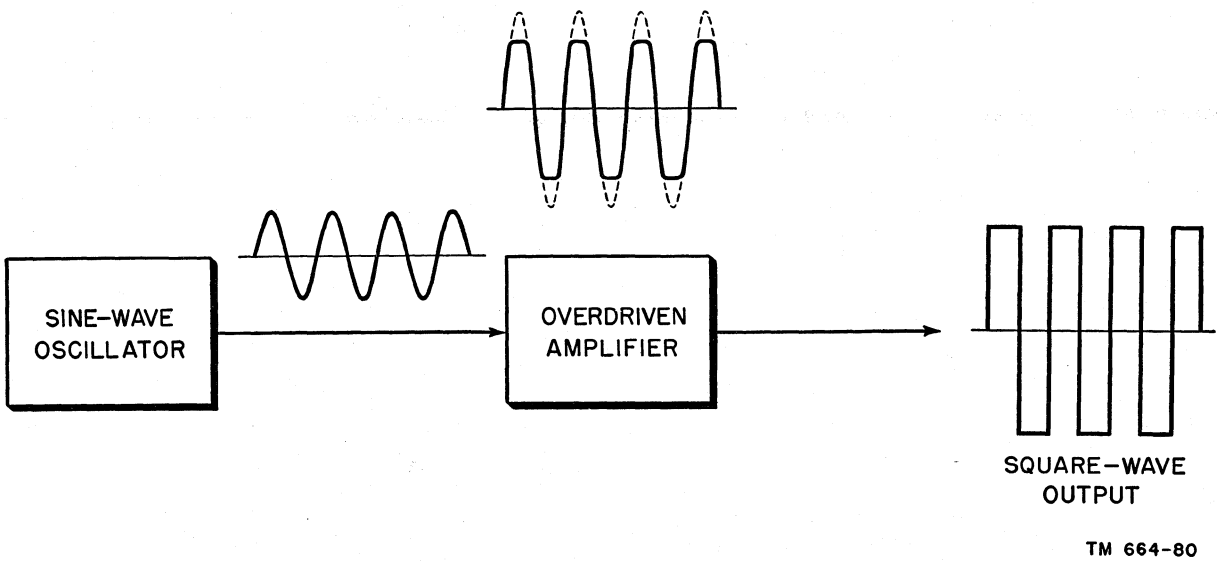


Figure 80. Square-wave production from sine waves.

(2) To check the frequency response of an amplifier, the square waves are fed to the amplifier input and an oscilloscope is attached to the amplifier output. The method of connection and the various output waveshapes that can result for different frequency responses are shown in figure 81.

64. R-F Signal Generator

a. COMPONENT CIRCUITS IN R-F GENERATORS. An r-f generator consists of a basic oscillator circuit that generates an r-f signal whose frequency is variable over the required range; amplifier circuits to build up the amplitude of the r-f signal; modulating circuits to produce the type of modulation desired; an attenuating circuit to provide any desired variation in the output; and a meter circuit to measure and indicate the signal output. These generators must be well shielded to prevent stray signal pick-up by the receiver. The signal voltage is fed to the receiver through the shielded output leads of the generator to prevent misleading results that can be obtained when making receiver sensitivity tests and similar performance tests.

b. A-M GENERATORS. Figure 82 shows a block diagram of an a-m generator. There are two oscillators, one for generating rf at the required frequency, and the other to generate an audio voltage. The audio voltage may be a set frequency (generally 400 cycles) or variable over the entire audio range. An amplitude-modulated signal is produced by combining the a-f and r-f signals in the mixer. This signal is then amplified in the amplifier section and fed to the attenuator. Generally, the a-m generator gives the technician a choice of three outputs: unmodulated rf (continuous wave), amplitude-modulated rf (modulated continuous wave), or a 400-cycle audio note. A-m generators can be used with both a-m and f-m receivers for alinement, receiver performance tests, trouble shooting, signal substitution, and signal tracing.

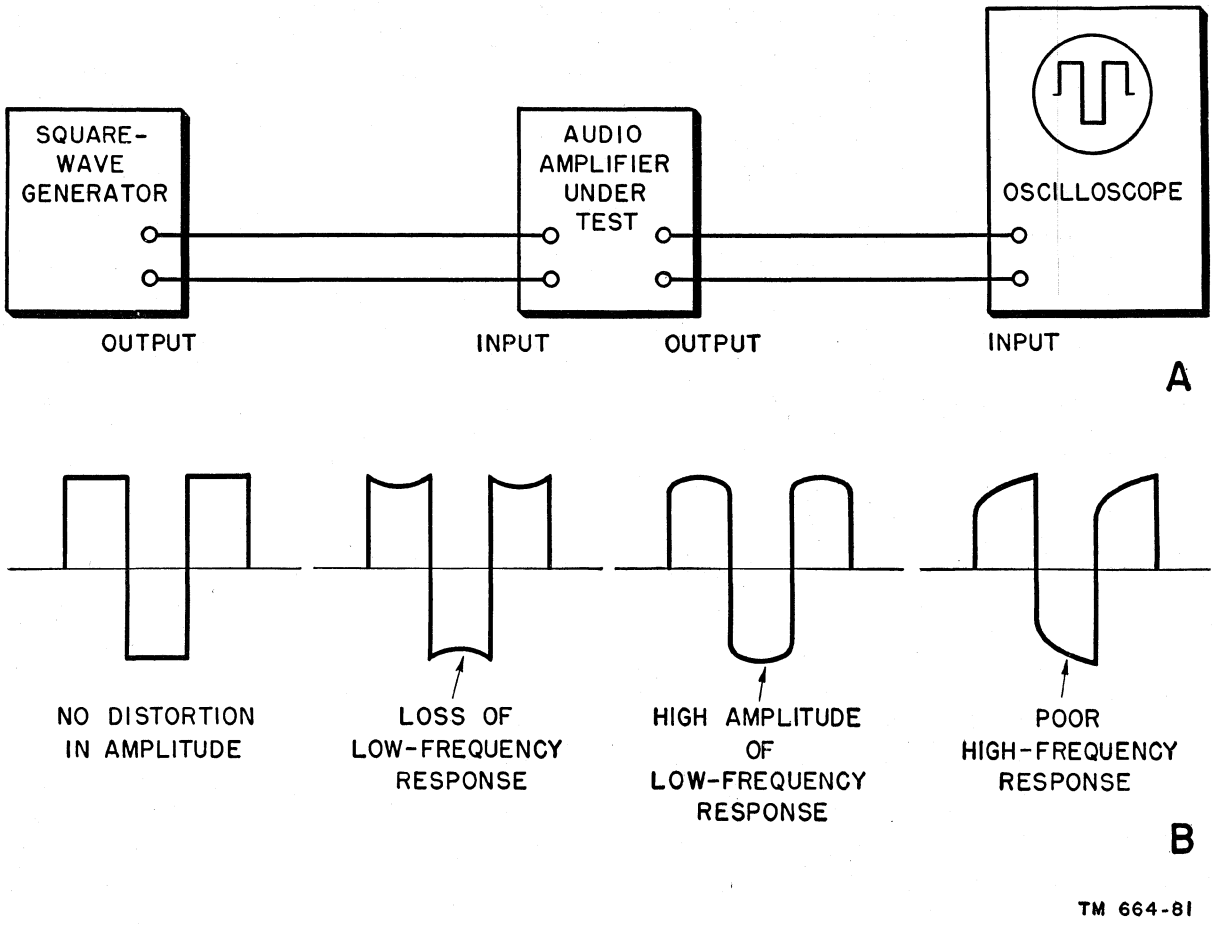


Figure 81. Square-wave testing amplifiers.

c. F-M GENERATORS.

(1) F-m generators provide an r-f signal that varies in frequency. When an audio signal is mixed with a radio frequency whose amplitude is constant, the rf changes in frequency at a rate determined by the instantaneous amplitude of the audio signal. On one alternation of the audio signal, the r-f frequency is higher than the resting, or original, frequency; on the other alternation of the audio signal, the radio frequency is lower than the resting frequency. The rf is no longer a steady frequency, but a shifting one, and the amount of frequency shift from the center frequency is called the *deviation.* The amount of deviation depends on the amplitude of the audio signal and the number of times per second it takes place depends on the frequency of the audio signal. The amount of deviation may vary from a few kilocycles to 10 megacycles or more.

(2) The basic unit of the f-m generator is an oscillator that generates a continuous rf at a given frequency. To obtain an f-m signal, there must be an audio signal that will cause the frequency of the rf to vary with it. One method of producing an f-m signal is to take a 60-cps audio signal from the filament winding of a power transformer and feed it through a potentiometer to the voice coil of a small permanent-magnet loudspeaker. By varying the resistance of the potentiometer which is in series with the

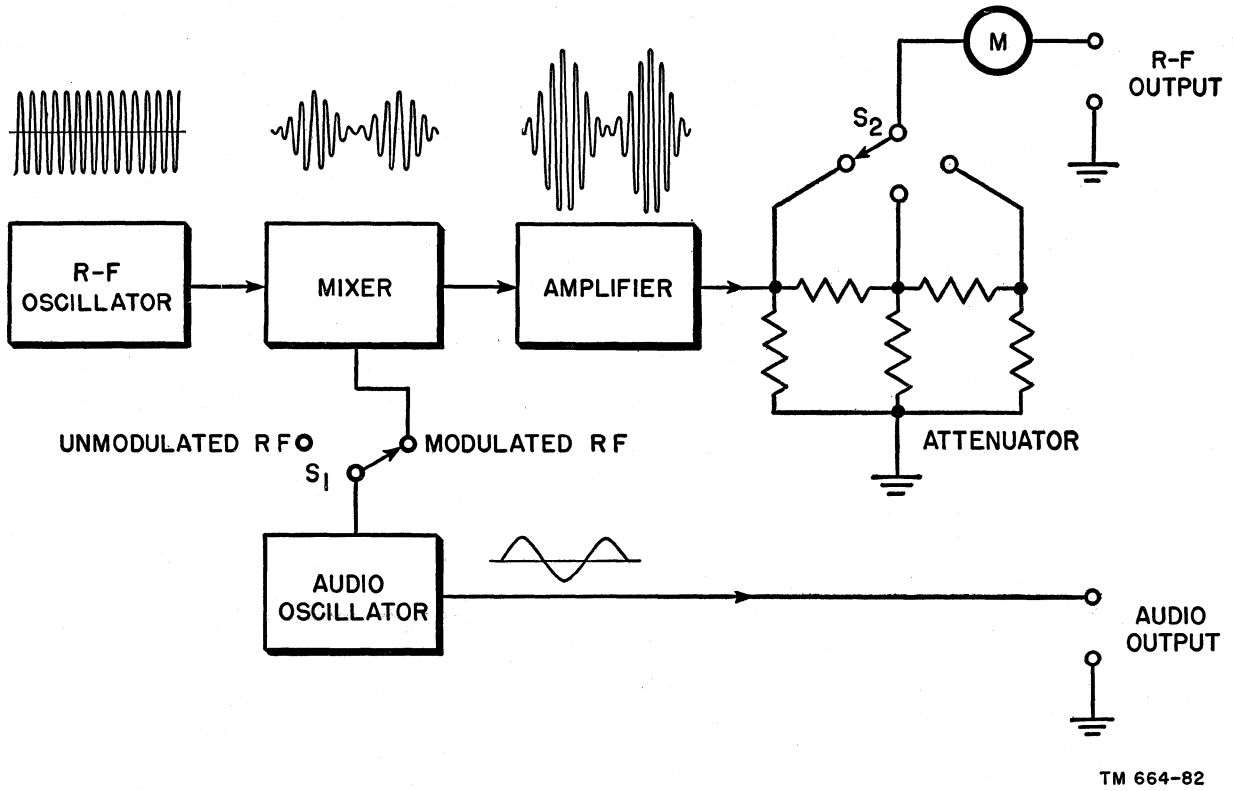


Figure 82. Block diagram of simplified a-m generator.

voice coil, the amount of vibration of the speaker cone can be varied.

(3) If a copper disk is attached securely to the speaker cone and mounted close to the coil of the r-f oscillator circuit, when the disk comes closer to the r-f coil, eddy currents are induced in the disk. The lines of force from the disk oppose the lines of force from the r-f coil. Therefore, the effective inductance of the coil will be reduced and the frequency of the tuned circuit becomes higher. When the disk moves away from the r-f coil on the other alternation of the audio cycle, the frequency change is in the opposite direction. The amount of frequency change can be regulated by adjusting the amount of vibration of the speaker cone. This is done by controlling the amplitude of the 60-cps input to the voice coil.

(4) To sum up, a 60-cps audio signal causes the f-m signal to vary on either side of the resting frequency 60 times per second. Also, the higher the amplitude of the audio signal, the greater the frequency deviation of the f-m signal. F-m generators are used for visual alinement of a-m, f-m, and television receivers, and alinement and testing of some types of radar receivers.

d. PULSE-MODULATED GENERATORS.

(1) In a p-m (pulse-modulated) generator, the rf is interrupted or pulsed at an audio-frequency rate. Controls are provided to vary the *pulse width* (duration of each pulse of rf) and the *repetition rate* (number of pulses per second).

(2) To pulse-modulate the r-f signal, a constant rf is generated in a conventional oscillator circuit. A square wave is generated in another circuit and both the rf and the square wave are fed to different grids of an amplifier tube. For example, the r-f signal is fed to the control grid, and the square wave is fed to the suppressor grid. The r-f

signal on the control grid is a continuous wave. The square-wave signal on the suppressor grid is first positive, and then negative. When the square-wave signal on the suppressor is negative, plate current is cut off and all of the tube current flows to the screen grid. When the suppressor grid has a positive square wave applied to it, current flows from cathode to plate.

(3) The plate current is controlled by the r-f signal on the control grid. Therefore, the current arriving at the plate is an r-f signal that lasts for the period of the positive square wave. The pulses then can be fed to one or more amplifier stages. The duration of the pulses and the number of pulses per second are varied by controls in the square-wave circuit.

(4) Pulse-modulated generators are useful in checking the performance of many kinds of radar receivers, since these sets usually send and receive signals in pulse form.

65. Alinement of A-M and F-M Receivers

a. REASONS FOR ALINEMENT. One of the major uses of the signal generator is receiver *alinement.* Alinement is the process of adjusting the tuned circuits of a radio receiver to the correct operating frequencies. The need for alinement can arise for one or more of the following reasons: aging of tubes; replacement of defective parts or tubes; change in the placement of wires; vibration; climatic conditions. *Alinement should not be attempted until other simple possibilities of trouble have been ruled out.*

b. SUPERHETERODYNE OPERATION. The superheterodyne receiver generally is used for a-m and f-m reception. A brief review of the operation of a typical a-m superheterodyne receiver (fig. 83) is offered to clarify the requirements for alinement. Incoming signals strike the antenna and set up magnetic fields around the r-f amplifier TC_1. The tuned circuit in TC_1 selects the desired r-f signal and prevents other signals from reaching the next stage. The selected signal then is amplified in the r-f stage and proceeds to the mixer stage. TC_2 in the mixer stage provides greater selectivity, allows the desired r-f signal to pass, and keeps out any other signals that may have been passed by the r-f stage. Tuned circuits TC_1 and TC_2, therefore, always are tuned to the frequency of the incoming signal. The tuned circuit of the oscillator stage, TC_3, is tuned to a definite frequency above or below the incoming frequency, and is fed to the mixer where it mixes with the incoming signal to produce new frequencies. These include the desired intermediate or difference frequency. For example, if the incoming signal is 1,000 kc and the oscillator frequency is 1,456 kc, the two signals will mix and produce an intermediate frequency of 456 kc (1,456 kc minus 1,000 kc = 456 kc). No matter what the frequency of the r-f circuits, the oscillator circuit is tuned so that it will produce the same intermediate frequency. Many other frequencies appear at the plate of the mixer stage, but only the intermediate frequency passes through to the next stage because TC_4 and TC_5, in the plate circuit of the mixer and grid circuit of the i-f amplifier, are tuned to the intermediate frequency. Tuned circuits TC_6 and TC_7 in the plate circuit of the i-f amplifier and input circuit to the detector are also tuned to this frequency. At the detector, the audio signal is separated from the intermediate frequency and passed through an audio-amplification stage to the speaker voice coil, which changes the electrical signals to sound.

c. ALINEMENT POINTS IN A-M RECEIVERS. The purpose of alinement in an a-m superheterodyn receiver is to tune the r-f circuits to the desired r-f range of the receiver, tune the local oscillator so that it tracks with the r-f circuits through the band, and tune the i-f circuits to the fixed intermediate frequency. TC_1 and TC_2 always must be tuned to the same frequency, and TC_3 must be tuned to a frequency different from TC_1 and TC_2 by the exact amount of the intermediate frequency. The i-f transformers, TC_4, TC_5, TC_6, and TC_7, are tuned to the desired frequency.

d. F-M RECEIVER ALINEMENT. In an f-m superheterodyne receiver, the i-f, r-f, and oscillator sections are alined in the same manner as the a-m receiver. The f-m detector, which is usually more complex than the a-m detector, requires an additional step in alinement. Spe-

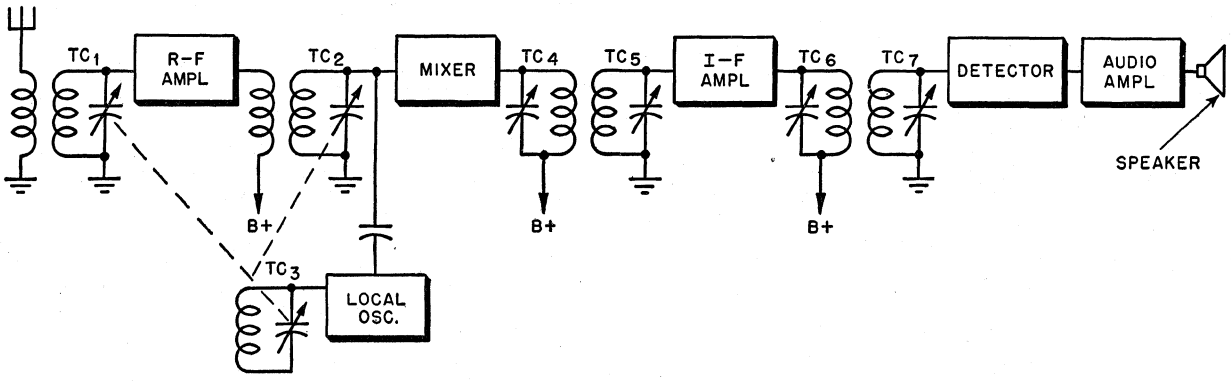


Figure 83. Outline of typical superheterodyne receiver showing tuned circuits.

cific alinement procedure for either f-m or a-m receivers is given in the technical manuals furnished with the equipment. The instructions should be followed closely.

e. DUMMY ANTENNA (fig. 84). The dummy antenna matches the impedance of the signal generator to the impedance of the receiver and serves as a convenient means of injecting the signal. It is placed between the hot lead of the signal generator and the receiver antenna terminal and should have the same electrical characteristics as the actual antenna. The dummy antenna to be used usually is specified in the receiver instruction manual.

f. OUTPUT INDICATION. In alinement, the output indicator is read for a maximum value of output. Therefore, the indicator can be connected at places other than across the output. One method is to connect the indicator to the plate of the power output tube. At this point, the audio signal has maximum voltage amplitude and when circuits are badly misalined, the output indicator will provide the most sensitive indication.

g. TYPES OF OUTPUT INDICATORS.

(1) Instruments used as output indicators during alinement show relative values of amplitude. The most popular instruments for this purpose are either the copper-oxide rectifier or vacuum-tube a-c voltmeters, output meters, or oscilloscopes.

(2) An output meter in either type of a-c voltmeter plus a capacitor in series with one lead for the purpose of keeping out d-c and allowing ac to pass.

(3) An output meter is used when an indication is to be taken at a point where both ac and dc are present, such as the plate of the power output stage. Although a-c meters respond to either ac or dc, only the a-c signal coming through the receiver is important for alinement purposes. Therefore, when a meter is used at the power amplifier plate, it should be an output meter rather than an a-c voltmeter. At the receiver output, where only ac is pres-

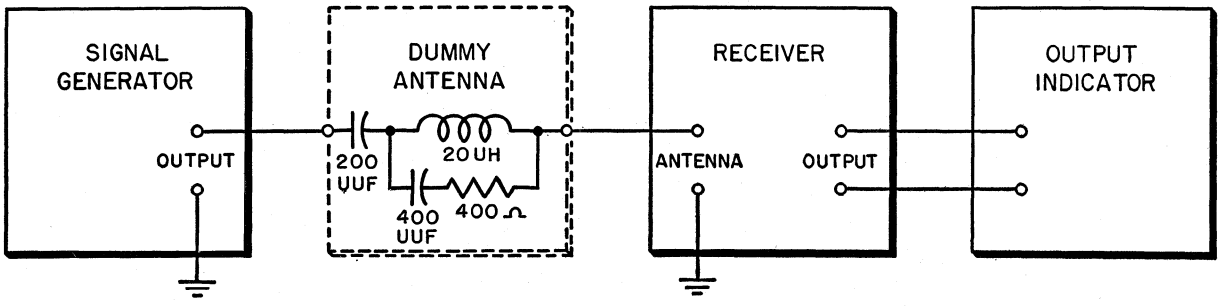


Figure 84. Dummy-antenna circuit connected between signal generator and receiver.

ent, either an a-c voltmeter or an output meter can be used.

h. OSCILLOSCOPE.

(1) An oscilloscope gives a visual indication on a crt (cathode-ray tube) of any a-c voltage waveform applied to the vertical input. An oscilloscope panel is shown in figure 85. The name and purpose of each control is indicated in table I. Because there is an internal coupling capacitor, the oscilloscope input leads can be placed at a point where there is only ac, or where there is both ac and dc.

(2) The oscilloscope can be used as an output meter, an a-c voltmeter, or a distortion meter. When it is used as an output indicator, the horizontal gain control can be set at 0. The output of the receiver, then, will show as a vertical line increasing in amplitude as the output increases (fig. 85). The trace is observed for maximum height without attempting exact measurement. The oscilloscope also can measure the exact amplitude of the a-c signal by first feeding a known voltage to the input and observing its exact height. The signal to be measured then is fed to the input and its amplitude is compared with that of the known voltage. The vertical amplitude control of the oscilloscope *is not to be varied* when the unknown signal is fed to the input. The oscilloscope can measure peak voltages, not only of sine waves but also of irregular waveforms that are almost impossible to measure accurately with any other kind of meter.

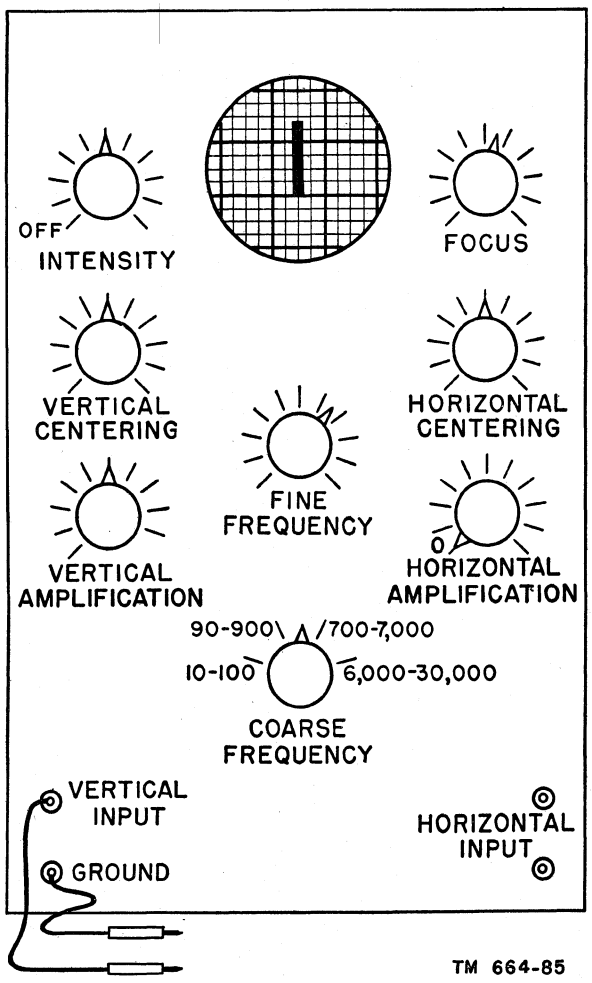


Figure 85. Typical oscilloscope.

Table I. Oscilloscope Controls and Functions

Control, jack, or switch	Function	Position for output indication or waveform observation
On-off switch	Turns power on or off	Intensity control is rotated clockwise to turn power on.
Intensity control	Varies brightness of trace	Adjusted for good visibility.
Focus control	Varies sharpness of trace	Adjusted for clear, sharp trace.
Vertical centering control	Varies vertical position of trace.	Control usually is centered, then readjusted if necessary.
Horizontal centering control	Varies horizontal position of trace.	Control usually is centered, then readjusted if necessary.
Vertical amplifier control	Varies vertical size of waveform.	Control is adjusted to desired vertical size.
Horizontal amplifier control	Varies horizontal size of waveform.	For output indication, control is set at zero so that only a vertical line appears. For waveform observation, control usually is set until horizontal size is just within limits of screen.
Frequency controls	Make observed waveform stand still.	Set at the same frequency as that of the signal being observed.

(3) A third use of the oscilloscope is as a distortion meter. Assume that the output of the receiver is distorted, and some point in the audio section is suspected. A sine wave at an audio frequency can be fed to the input of the audio section. The oscilloscope then can be connected in turn to each of the audio stages to find at which point the distortion is developing.

i. VISUAL ALINEMENT OF A-M AND F-M RECEIVERS. A-m and f-m receivers can be alined visually by using an f-m generator and an oscilloscope. Visual alinement, however, is somewhat more difficult and not necessarily more accurate than the basic alinement method described above, which uses an a-m signal generator and an output indicator.

66. Receiver Servicing

a. USE OF SIGNAL GENERATOR IN SERVICING. There are two general methods of using signal generators for servicing defective receivers—signal substitution and signal tracing. When a receiver develops trouble and the cause of the defect is not immediately apparent, the first step is usually to test the tubes. If this does not clear up the trouble, the standard procedure in trouble shooting is to find the defective stage by either the signal substitution or the signal tracing method.

b. SIGNAL SUBSTITUTION.

(1) In signal substitution the signals from the generators are applied to each stage of the receiver to determine whether the stage can pass the signal. For example, to check the operation of the audio section, an a-f signal is injected at the grid of the audio output stage. If the stage passes the signal it is assumed to be in working order and the generator is moved to the plate of the preceding audio stage, then to the grid, until the entire audio section has been covered. If the signal is passed along and amplified from each point, the a-f stages are operating and the i-f stages should be checked.

(2) A modulated i-f signal is applied to the i-f section, starting with the plate of the last i-f stage. Then work back to the mixer plate, listening for the modulation output at the speaker. If the i-f stages pass the signal, the mixer, oscillator, and r-f stages must be checked.

(3) Apply the modulated r-f signal to the grid of the mixer stage and note whether the signal appears at the receiver output when the set is tuned to the signal frequency. If this stage is operating, work back through the r-f stages to the antenna terminal. When the r-f signal does not appear at the output of the mixer, the oscillator stage should be checked for operation. A simple way to determine oscillator operation is to check the negative voltage on the grid. The minimum usually necessary for operation is —5 volts; however, the amount of negative voltage varies with different receivers and should be checked against the instruction manual. If any stage fails to pass a signal when using signal substitution, the trouble is localized in that stage. The individual parts for that stage should then be checked for defects.

c. SIGNAL TRACING.

(1) The second method for localizing trouble is signal tracing. This method is similar to signal substitution, but the procedure starts at the antenna terminals of the receiver instead of the audio output stage.

(2) In signal tracing, a signal generator supplying a modulated r-f signal of predetermined amplitude is connected to the antenna terminals of the receiver. This signal is then followed or traced through various stages of the receiver by connecting an indicating device first to the input and then to the output of each succeeding stage. The point where the signal disappears indicates the defective stage, and the individual parts within that stage should be checked.

(3) Indicator units used in signal tracing should be suitable for the circuit under test. The audio-amplifier stages require an output meter, speaker, or

oscilloscope as an indicator. Amplifiers operating at radio frequencies require a test instrument that provides an indication at radio frequencies. These can be r-f vtvm's, r-f oscilloscopes, detectors with an audio amplifier, or special signal-tracing equipment.

d. SIGNAL-TRACING CHARTS. In receivers that operate but do not meet sensitivity specifications, the signal-tracing method is often used to measure the relative gain of the signal through each successive stage of the receiver. Receiver instruction manuals usually contain signal-tracing charts which give information on where to apply the input signal, what amplitude the input signal should be, where to connect the indicating device, and the indication that should be obtained if the stage is operating properly. With this information, the trouble can be localized quickly to a specific stage. Then the individual parts within the stage can be checked for defects. The signal substitution method also can be used to localize trouble in weak receivers if calibrated audio and r-f signal generators are used to inject a signal of the frequency and amplitude specified in the signal-tracing chart.

67. Summary

a. A signal generator produces a-c voltages at various frequencies. There are audio-frequency generators and radio-frequency generators.

b. A-f generators have either a sine-wave output or a square-wave output.

c. R-f generators can have an a-m, f-m, or a pulse-modulated output.

d. Signal generators are used for receiver alinement, receiver performance tests, and receiver servicing.

e. The basic stage in all signal generators is the oscillator stage.

f. An r-f oscillator is a vacuum-tube amplifier circuit consisting usually of a tuned circuit, L and C, with proper feedback to sustain oscillations.

g. A crystal oscillator uses a quartz crystal instead of an L-C circuit in the grid of the oscillator stage.

h. A crystal oscillator is the electrical equivalent of a tuned-plate tuned-grid oscillator and uses capacitive feedback from plate to grid to sustain oscillation.

i. Crystals operate on the principle of piezoelectricity, the generation of voltage by the compression and expansion of the crystal under mechanical strain. Conversely, the crystal expands and compresses when a voltage is placed across it.

j. Sine-wave audio oscillators are useful in checking the frequency response of audio amplifiers.

k. Square-wave generators can be used to check amplifier frequency response by observing the output waveshape on an oscilloscope.

l. R-f signal generators usually consist of a basic oscillator circuit, amplifier circuits, modulating circuits, attenuating circuit, and meter circuit.

m. Alinement is the adjustment of the tuned circuits of a receiver to their correct frequencies.

n. One method of alining both a-m and f-m receivers is to use an a-m signal generator and an output indicator.

o. Output indicators used for a-m receivers are a-c voltmeters, output meters, and oscilloscopes.

p. When f-m receivers are alined with an a-m generator, the output indicator used generally is a vtvm.

q. When a signal generator is used to inject a signal into a receiver at the antenna terminals, a dummy antenna is put in series with the hot generator lead.

r. To service receivers, a signal generator can be used for signal substitution or signal tracing.

s. Signal substitution is the process of injecting a signal of the correct frequency into each stage. It is customary to start at the last audio stage and work back to the antenna.

t. Signal tracing starts at the antenna terminals with a given value of input signal from the generator. Then an indicating device is used at each stage, working back to the speaker, to find where the signal is lost or not amplified sufficiently.

68. Review Questions

a. What is a signal generator?

b. Classify a-f generators by type of output.

c. Classify r-f generators by type of output.

d. What are the main uses for signal generators?

e. Define damping, tuned circuit, resonant circuit.

f. A tuned circuit is connected across a battery for an instant. Describe what occurs.

g. What factors govern the frequency of oscillation and damping?

h. List the factors necessary for sustained oscillation in any oscillator.

i. Define piezoelectricity.

j. What are the advantages and disadvantages of crystal oscillators?

k. How are square-wave generators used to check amplifier frequency response?

l. List the basic circuits in r-f generators.

m. Why is shielding important in r-f signal generators?

n. Draw a block diagram of an a-m generator.

o. Define pulse modulation, pulse width, pulse repetition rate.

p. List five conditions which can make receiver alinement necessary.

q. Why are dummy antennas used?

r. List three output indicators for use in alining an a-m receiver and where each can be applied.

s. Describe signal substitution in receiver servicing.

t. Describe signal tracing in receiver servicing.

SECTION X

FREQUENCY MEASUREMENT

69. Introduction

Indirect methods of measuring frequency by means of signal generators, oscilloscopes, and output meters have been discussed in previous chapters. Frequency or wavelength, however, may be determined also by frequency-measuring devices, known as *wavemeters* or *beat frequency meters*. These meters indicate the fundamental or harmonic frequencies of oscillators or harmonic generators on a calibrated dial. The wavemeter is calibrated in terms of wavelength, and contains a variable tuned circuit whose resonant frequency is determined by the unknown frequency. The beat or heterodyne frequency meter uses an oscillator to generate signals of known frequencies and compares these with the unknown frequency.

70. Wavemeters

There are two basic wavemeters, both of which absorb part of the output power of the device whose frequency is to be measured. The *reaction wavemeter* absorbs very little power, and an ammeter, located in the circuit of the device whose frequency is to be measured, usually serves as an indicator. Since the power absorbed is not sufficient to load the equipment being measured to any great extent, it can be used to measure the frequency of low-power equipment. The *absorption wavemeter* is more accurate than the reaction wavemeter and absorbs slightly more power from the equipment whose frequency is being measured. It generally is used on high-power equipment only, since it tends to load the equipment. An ammeter, a lamp, or an earphone is used to indicate the unknown frequency.

a. REACTION WAVEMETER.

(1) The basic circuit of a reaction wavemeter containing a coil, L, and a variable capacitor, C, is shown in figure 86. The external coil, L, is loosely coupled to the output coil of the device whose frequency is to be measured. The capacitor, C, then is tuned until the resonant frequency of the wavemeter is equal to the frequency of the device under test. At this point the ammeter indicates resonance which can be either maximum or minimum, depending on where the ammeter is located in the device under test. The capacitor is operated by an accurately calibrated vernier dial, with the graduations in terms of some arbitrary unit. The frequency or wavelength is found by means of a calibration curve or chart which relates the dial setting to either frequency or wavelength.

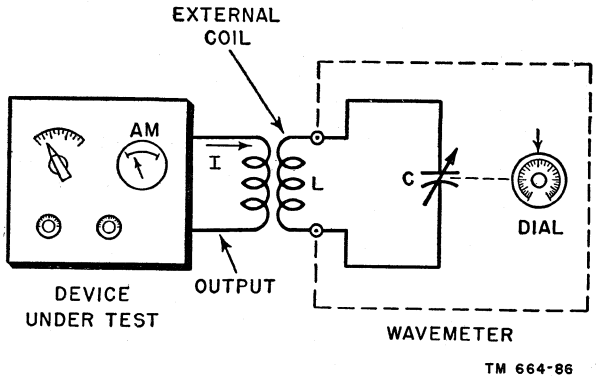


Figure 86. Basic circuit of reaction wavemeter.

(2) When the wavemeter is moved into the r-f field of the device under test, the coupling produces a change in the current, and increases the load on the device. When the wavemeter is tuned to resonance, this load becomes maximum, and the indicating ammeter reads a minimum or maximum, de-

pending on its location. To prevent loading of the equipment being measured, the wavemeter is moved away until the least possible variation of the tuning capacitor causes a maximum deflection on the meter (curve A, fig. 87).

(3) A plot of output current versus wavemeter frequency for various degrees of coupling is shown in figure 87. When the wavemeter is resonant, the load on the device is a maximum and the current is a minimum. The dips in the curves indicate a dip in the reading of the ammeter. Curve A indicates loose coupling (the wavemeter has been moved away from the equipment being measured). As the coupling is increased, the dip in primary current becomes greater. Curve B represents tight coupling, curve C critical coupling, and curve D overcoupling. *For accurate frequency measurements, the coupling is decreased until there is a very small dip in the current meter.* Loose coupling is ideal for accurate frequency measurements, since its dip at resonance is very sharp.

b. ABSORPTION WAVEMETER.

(1) Although the absorption wavemeter is similar to the reaction wavemeter, it contains also a resonant-frequency indicating device. Figure 88 shows an absorption wavemeter circuit using a lamp to indicate resonance. The functions of tuning capacitor C_1 and external coil L are identical with those explained in the discussion of the reaction wavemeter. The lamp is at maximum brilliance when the wavemeter is at the resonant frequency of the device under test. The amount of brilliance that results is dependent on the voltage appearing across fixed capacitor C_2. The capacitive value of C_2 is much larger than that of C_1, and, since its reactance is negligible at the resonant frequency, C_1 and L determine the resonant frequency of the wavemeter.

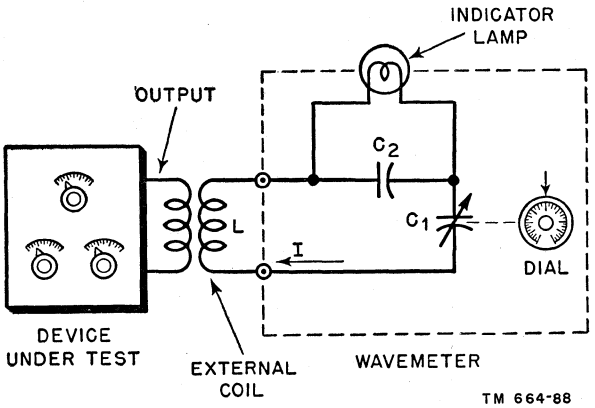


Figure 88. Basic circuit of absorption wavemeter.

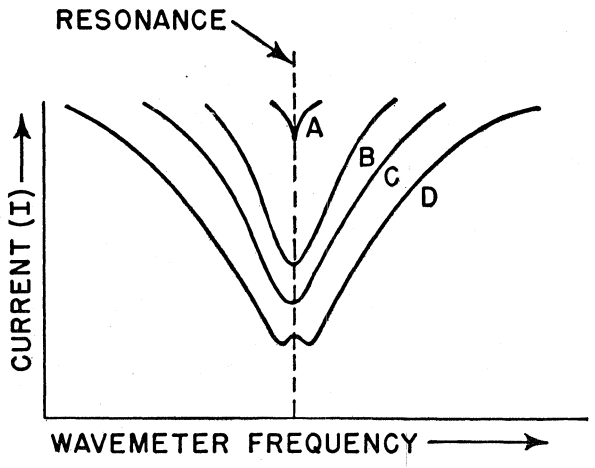


Figure 87. Coupling effects on output current using reaction wavemeter.

(2) When the wavemeter circuit is tuned to the same frequency as the unknown frequency, a maximum circulatory current flows in the wavemeter circuit. Since this circulatory current occurs at resonance and current is maximum at resonance, voltage drops appear across L, C_1, and C_2 and the voltage drop across C_2 causes the lamp to glow. As C_1 is tuned to either side of resonance, the circulatory current becomes less and the lamp grows dimmer.

(3) In figure 89, the circulatory current is plotted against the wavemeter frequency for various degrees of coupling. For accurate frequency measurements, the external coil of the wavemeter is

loosely coupled to the device under test. This accuracy is indicated by the sharpness of curve C at resonance. Although overcoupling, as shown in curve A, produces a greater circulatory current and lamp brilliance, it results in inaccurate frequency measurements. Overcoupling results in a double-humped curve where a maximum circulatory current is obtained on either side of resonance.

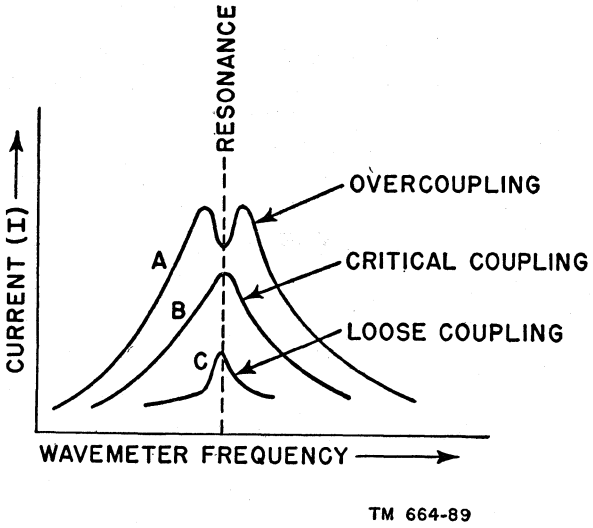


Figure 89. Coupling effects on circulatory current in absorption wavemeter.

(4) In A of figure 90, the headphones of the absorption wavemeter are coupled to the wavemeter circuit by means of small pick-up coils and are used as the indicating device. Resonance is obtained when a *click* is heard in the headphones as C_1 is tuned slightly above and slightly below resonance. The crystal rectifier is used to obtain the direct current necessary to operate the headphones.

(5) In B, a d-c meter movement replaces the headphones, a diode rectifier replaces the crystal, and the circuit operates as a simple vacuum-tube voltmeter. The diode is a filament-type tube operated by means of a small self-contained battery. Resistor R_1 is used to adjust the filament voltage to its proper value. Capacitors C_2 and C_3 bypass the r-f circulatory current around the ammeter and battery. The ammeter reads in direct proportion to the potential difference existing across tuning capacitor C_1. This potential

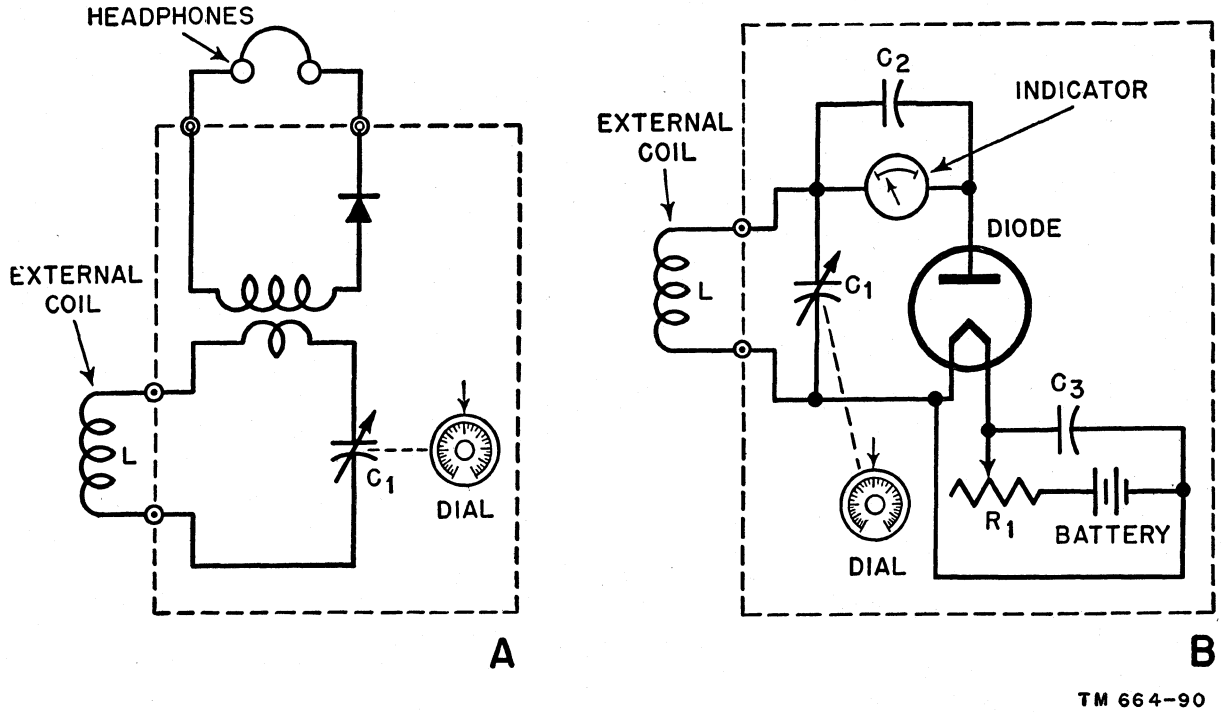


Figure 90. Circuit variations of absorption wavemeter.

difference results from the circulatory current in the wavemeter circuit and, at resonance, the ammeter reads maximum.

c. DETERMINING UNKNOWN FREQUENCY.

(1) In the reaction wavemeter, the frequency to be measured is determined in the following manner: The external coil of the wavemeter is moved into the r-f field of the device whose frequency is to be measured. The knob on the dial setting then is slowly rotated through its frequency range until some reaction is noted on the *indicating meter in the device under test.* The wavemeter is moved slowly away from the oscillator until the deflection on the indicating meter is barely perceptible. The dial setting knob now is adjusted for a maximum deflection on the meter.

(2) In the absorption wavemeter, the frequency to be measured is determined in a similar manner. A lamp is used as an indicator, and the wavemeter is brought near the device under test. The dial setting knob is turned slowly through its range until the indicator lamp just begins to glow. The knob is not turned for maximum lamp brilliance, which might cause it to burn out. The wavemeter is moved slowly away from the oscillator until the lamp glows more dimly or goes out. It then is tuned for maximum lamp brilliance. For accuracy, the wavemeter should be taken as far from the device as possible, where maximum brilliance is a faint glow.

(3) Wavemeters usually contain several external coils of the plug-in variety. Each coil represents a specific frequency range, and if the *approximate* frequency to be measured is known, the selection of the proper coil is simplified. Where the approximate frequency is unknown, each coil must be tried separately to obtain resonant indications. The tuning capacitor is of the air type and the frequency range it covers determines the number of plug-in coils that are needed. A *frequency standard,* from which a fixed known frequency signal can be obtained, is used to calibrate the wavemeter, as discussed in paragraph 72.

(4) Many wavemeters use a micrometer-type tuning dial. The micrometer consists of a thimble with a vernier scale which is rotated about a barrel with a coarse scale. A typical micrometer dial (A of fig. 91) is read in the following manner: The barrel has major divisions marked on it which represent tenths of an inch or any desired unit that may be represented by tenths of an inch. Each of the four minor divisions between the major divisions represents .025 inch. The thimble is divided into 25 parts around its circumference, and one full rotation moves the thimble one minor division on the barrel or .025 inch. Since the thimble is divided into 25 parts, one division is equal to .025/25 or .001 inch. Consequently, the reading of the micrometer setting in A of figure 91 is .1 plus (.025 times 3) plus .009 = .184 inch. The frequency which represents a reading of .184 inch then is obtained from a calibration chart, shown in B, and is found to be 2,655 mc. The calibration chart, which represents a frequency range from 2,400 to 3,400 mc for micrometer readings from .0557 to .46, is on a metal plate screwed to the back of the wavemeter case.

71. Heterodyne Frequency Meter

a. PRINCIPAL OF OPERATION.

(1) When greater stability and accuracy are desired in direct frequency measurements, the *heterodyne,* or *beat,* frequency meter is used. The basic heterodyne meter (fig. 92) consists of a frequency-calibrated oscillator which beats, or heterodynes, against the frequency to be measured. The pick-up antenna is coupled loosely to the device under test. The calibrated oscil-

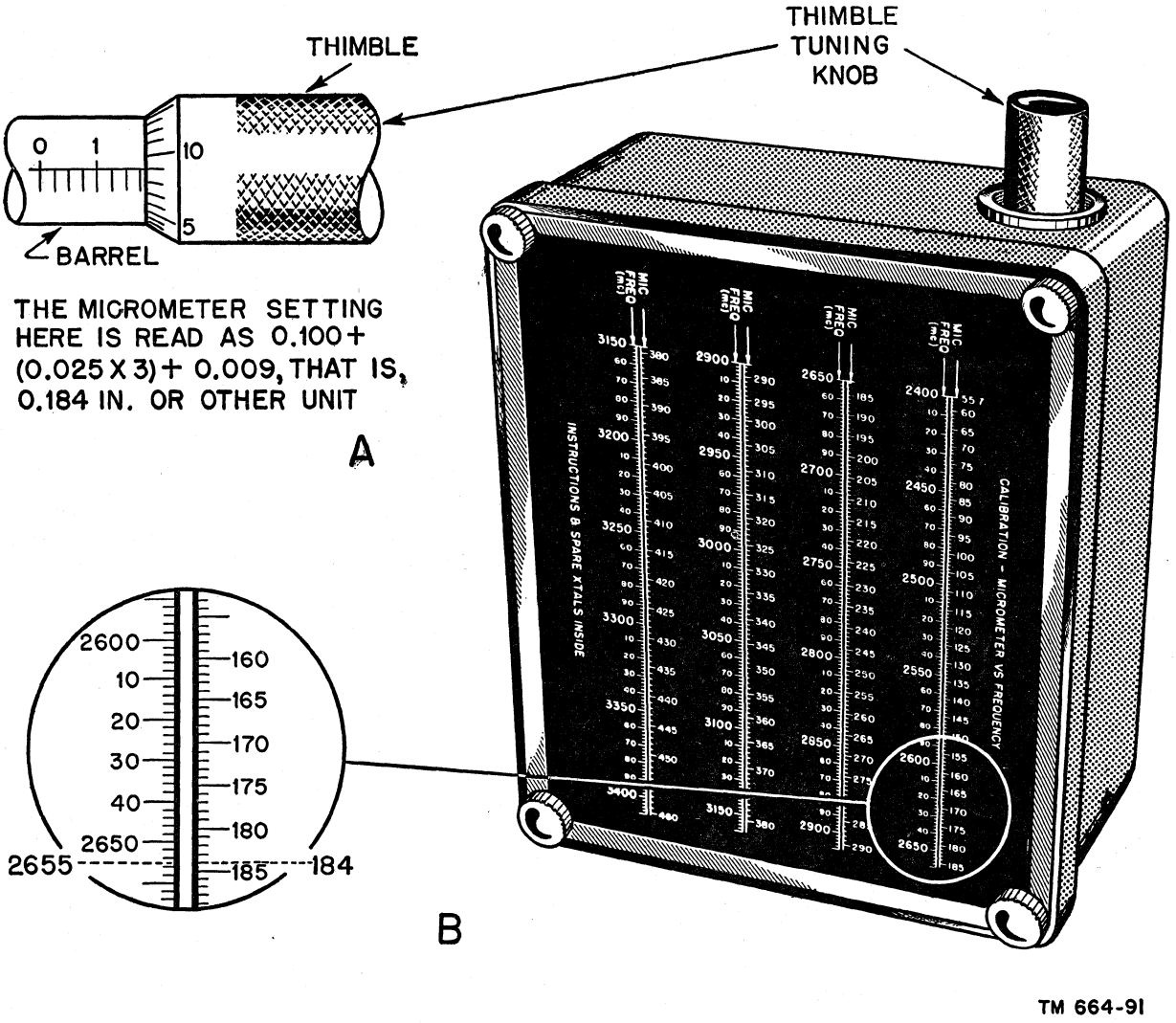


Figure 91. How to read a micrometer.

lator then is tuned so that the difference in frequency between the oscillator and the unknown frequency is in the a-f range. This difference in frequency is known as the *difference* or *beat* frequency and when it is detected and amplified it can be heard in the headphones. If the dial setting of the calibrated oscillator is tuned to the same frequency as the device under test, the difference frequency is zero, or *zero-beat frequency,* and no audible sound is heard in the headphones. When zero-beat frequency is obtained, the position of the pointer on the dial setting represents the unknown frequency.

(2) Figure 93 shows a curve of the beat frequency plotted against the audible range of frequencies. When the difference frequency between the two signals is above the audible range, no sound is heard and the shaded area on the graph indicates the frequencies above audibility. As the two frequencies are brought closer to each other (A on the curve) a high-pitched note is heard in the headphones. This tone gradually decreases in frequency to a point, B, where it is replaced by a

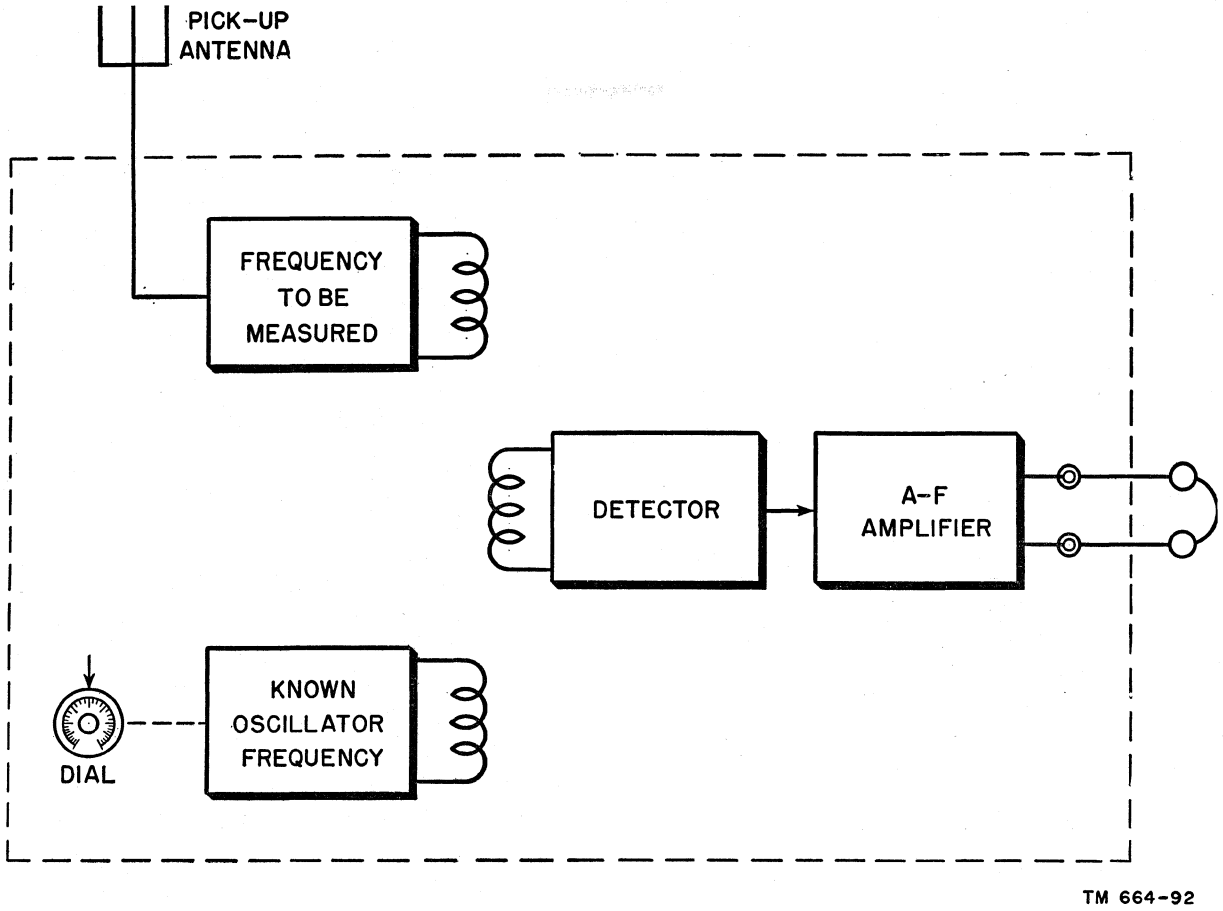


Figure 92. Block diagram of basic heterodyne frequency meter.

series of rapid clicks and the difference frequency is then only a few cycles per second. At C, the clicks have stopped completely, the two original frequencies are equal to one another, and this is the exact point of *zero-beat.* Clicks are heard at rather infrequent intervals at point C, since it is difficult to maintain a condition of absolute silence in the headphones over a prolonged interval of time because of a certain amount of circuit instability. As the standard oscillator frequency is varied beyond the zero-beat point, the number of clicks increases to point D. A low-pitched tone again is heard at this point, and varying the frequency in the same direction causes a gradual increase in frequency until point E is reached, where the beat note is again inaudible.

b. CALIBRATION.

(1) Most heterodyne frequency meters contain a stable crystal oscillator which is used for calibrating the frequency of the variable oscillator. The crystal oscillator produces a number of harmonics permitting calibration of the meter at various frequencies. These points of calibration are called *crystal check points* and the frequencies at which they occur are given in a *calibration book* which is used to determine the frequency of the dial setting.

(2) Figure 94 shows a typical arrangement for calibrating a variable-frequency oscillator. Assume that the calibration book shows a crystal check point at a frequency of 3,000 kc. The dial setting of the variable-frequency

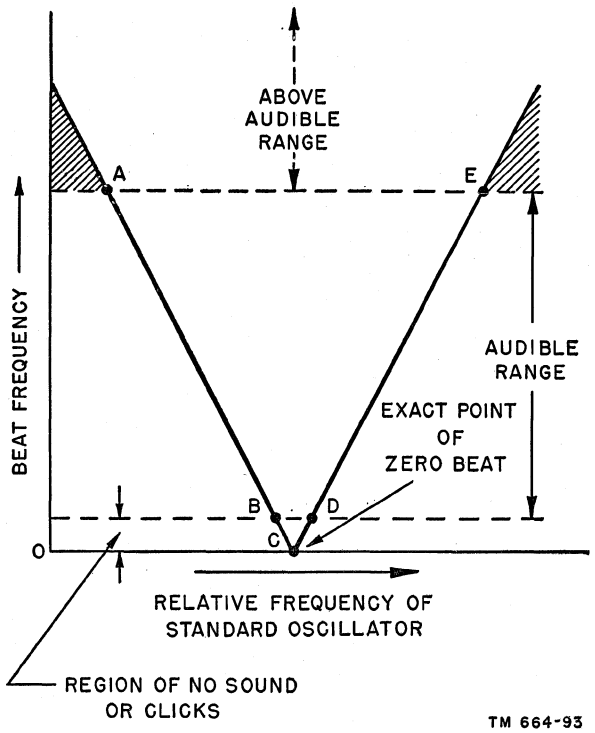


Figure 93. Beat-frequency chart.

oscillator is adjusted to represent a frequency of 3,000 kc. If the second harmonic of the 1,500-kc crystal oscillator (3,000 kc) zero-beats against the 3,000-kc output of the variable-frequency oscillator, the output frequency is zero. There is no sound in the headphones, the variable-frequency oscillator already is calibrated, and no compensating adjustment is necessary.

(3) However, if the output of the variable-frequency oscillator is some other frequency than 3,000 kc when the dial is set to 3,000 kc, the variable-frequency oscillator must be calibrated. If it is set at 3,000 kc and the actual frequency is 2999.7 or 3.000.3 kc, the output of the detector then will produce a beat frequency of .3 kc, or 300 cycles, that can be heard in the headphones. The corrector control, usually a small variable capacitor, then is adjusted until the frequency of the variable-frequency oscillator changes to 3,000 kc. When this is done, no audible tone is heard in the headphones and the variable-frequency oscillator has been calibrated. This procedure can be used for all crystal check points listed in the calibration book. *Before* making a correction in the calibration, the frequency meter should be turned on and allowed to warm up for 15 to 20 minutes to permit the operating temperature within the meter to become stable.

BASIC PRACTICAL CIRCUIT.

(1) A basic circuit of the heterodyne frequency meter is shown in figure 95.

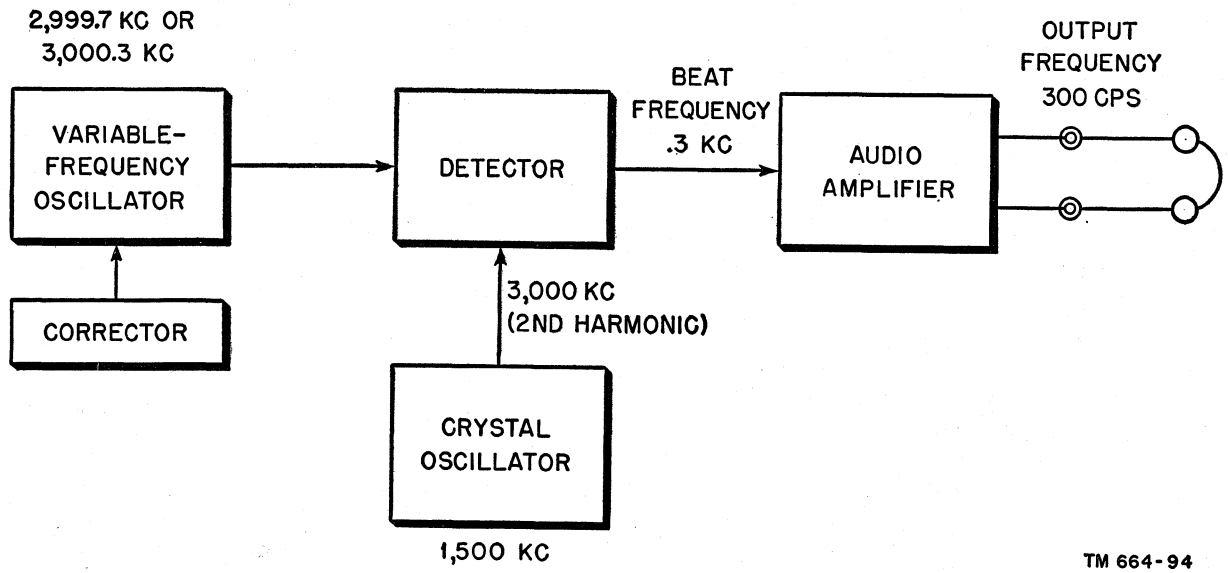


Figure 94. Typical arrangement for calibrating a frequency oscillator.

The circuit of tube V_1 is the variable-frequency oscillator whose output beats against the unknown frequency entering by way of the pick-up antenna. The circuit containing V_2 is the mixer stage to mix these signals, and serves also as a pentagrid converter when the variable oscillator is being calibrated. During calibration, the crystal oscillator is in the control-grid circuit of V_2 and the output of V_2 is fed to an a-f amplifier, V_3, which drives the headphones.

mer capacitor that *corrects* for frequency deviation when the variable oscillator is being calibrated.

(3) With switch S_2 in the OFF position, the control grid of V_2 is grounded, and V_2 becomes a mixer stage. It mixes the output of V_1, which is coupled through capacitor C_8, and the unknown frequency, which is coupled through C_7. When it is desired to calibrate the variable oscillator, S_2 is placed in the ON position, and V_2 becomes a pentagrid converter with the

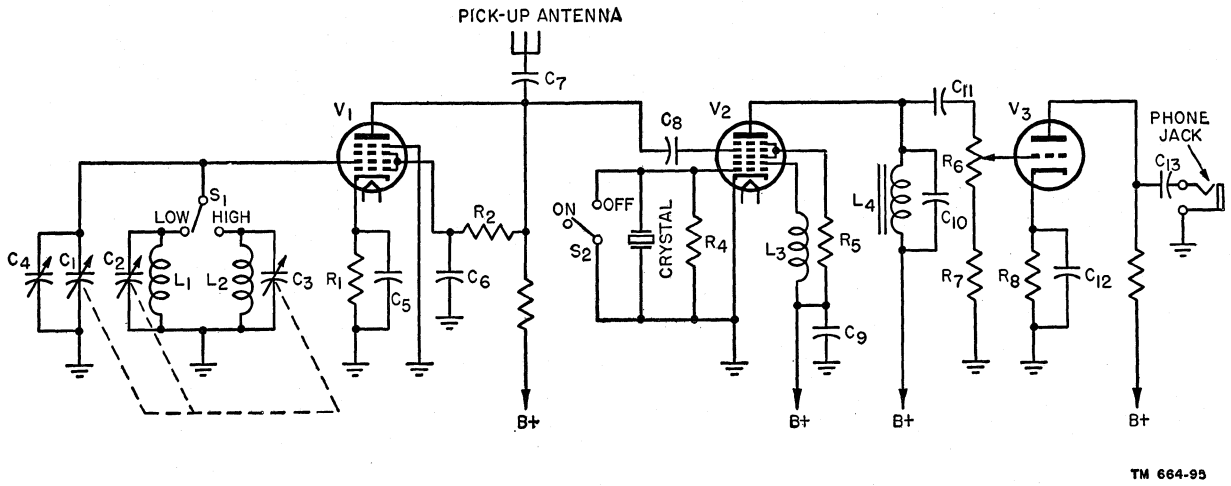


Figure 95. Basic practical circuit of heterodyne frequency meter.

(2) The circuit of V_1 forms an electron-coupled oscillator which has good stability under varying load conditions. Switch S_1 permits the oscillator to operate on two different frequency ranges. With S_1 in the low-frequency position, L_1C_2 determines the natural oscillator frequency. With S_1 in the high-frequency position, L_2C_3 determines the natural oscillator frequency. C_2 and C_3 are variable and cover the entire low- and high-frequency ranges, respectively. C_1 changes the natural frequency of the oscillator on both frequency ranges but to a lesser degree than C_2 and C_3. C_1, C_2, and C_3 are ganged together and are varied by the frequency tuning knob on the dial setting. C_4 is a trim-

cathode and the two grids directly above it, constituting a crystal oscillator, and the remaining electrodes forming a mixer stage. The output of V_2 is coupled through C_{11} to V_3, and the output of this tube is fed to the headphones. Resistor R_6 controls the the sound output in the headphones by varying the input voltage to V_3.

d. CONTROL PANEL.

(1) The control panel of a heterodyne frequency meter is shown in figure 96. When the LOCK screw is loosened, the tuning knob can be rotated to obtain various settings on the dial. The dial is calibrated in hundredths, units, and tenths for accurate readings. Rotating the dial changes the resonant frequency of the variable-frequency oscil-

lator by varying capacitor C_1, C_2, and C_3. When calibrating, the CRYSTAL OFF-ON switch, S_2, is turned to the ON position. The CORRECTOR control varies capacitor C_4 and compensates for any deviation of the variable-frequency oscillator. The FREQ BAND switch, S_1, selects the frequency range in which the meter is to be operated. Typical frequency ranges are 125 to 2,000 kc in the low-frequency band and 2,000 to 20,000 kc in the high-frequency band. The GAIN control, R_6, varies the intensity of the ouput signal heard in the headphones.

(2) The dial setting in figure 96 can be read in the following manner: The thin line marked on the window of the HUNDREDS dial indicates the *approximate* reading of the dial. Since it is situated between 3,800 and 3,900, the ultimate dial reading must lie between these numbers. The reading on the UNITS dial is read directly below the arrow on the TENTHS vernier. To obtain the reading, which lies between 76 and 77, the TENTHS vernier must be read. The tenths value is obtained from the dial by finding the line on its scale which coincides most closely with a line on the UNIT dial. The value of .7 on the TENTHS dial corresponds with 83 on the UNIT dial; therefore, the reading obtained on the dial setting shown in figure 96 is 3,800 plus 76 plus .7, or 3,876.7. The frequency reading that corresponds to this number must be obtained from a calibration book which is included with each frequency meter.

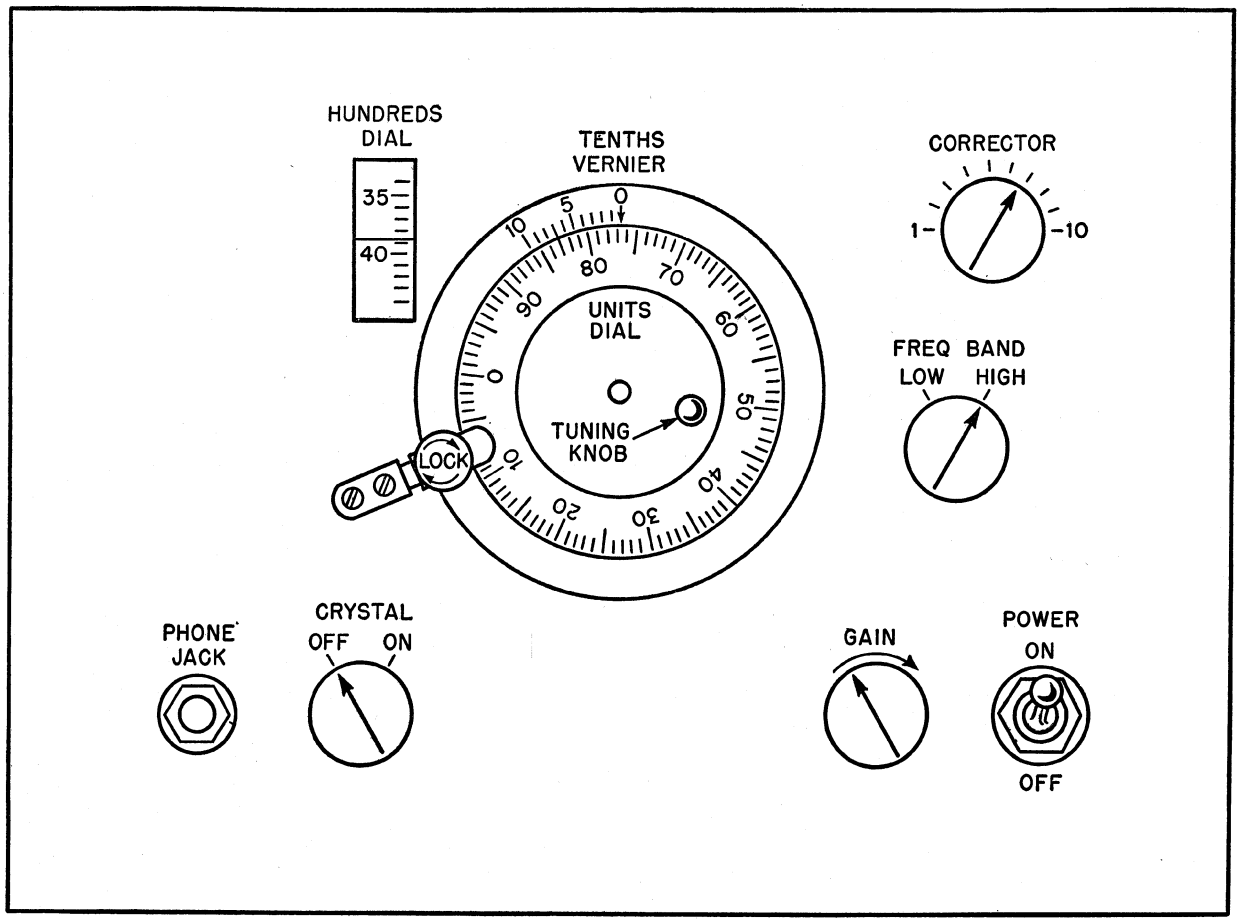


Figure 96. Typical control panel of heterodyne frequency meter.

e. CALIBRATION BOOK.

(1) Two typical pages of a calibration book are shown in figure 97. The pages are divided into DIAL and FREQUENCY columns and each dial setting corresponds to four different frequencies. The frequency column immediately following the dial setting represents the fundamental frequency of the variable oscillator. For example, a dial reading of 3,904.3 (fig. 97) indicates that the fundamental frequency of the variable oscillator is 3,660 kc. The other three frequency columns correspond to the harmonics generated by the variable oscillator. Consider an oscillator under test whose frequency output is approximately 14,000 kc. When determining its exact frequency output by means of a frequency meter, a dial reading of 3,942.2 is obtained. Looking in the third frequency column in the calibration book, the exact oscillator frequency is seen to be 14,704 kc.

(2) At the bottom of each page are the words NEAREST CRYSTAL CHECK POINT. The three numbers immediately following these words are the crystal check points nearest the desired frequency, and represent harmonics of the crystal oscillator.

(3) The observed dial setting may fall between two values listed in the calibration book. To aid in the calculation of the frequency corresponding to an intermediate dial setting, the following method, called interpolation, is used. The dial reading shown in figure 96 is 3,876.7. The calibration book (fig. 97) shows that this reading lies between the dial settings of 3,875.7 and 3,878.1.

	Dial setting	
	3,875.7	
diff = 2.4	3,876.7	
	3,878.1	diff = 1.4.

The fundamental frequencies of these two dial settings are 3,648 and 3,649 kc.

	Frequency	
	3,648	
Diff = 1 kc	*unknown freq.*	diff = x kc.
	3,649	

Therefore, a proportion is set up in the following manner:

$$\frac{1 \text{ kc}}{x \text{ kc}} = \frac{2.4}{1.4}$$

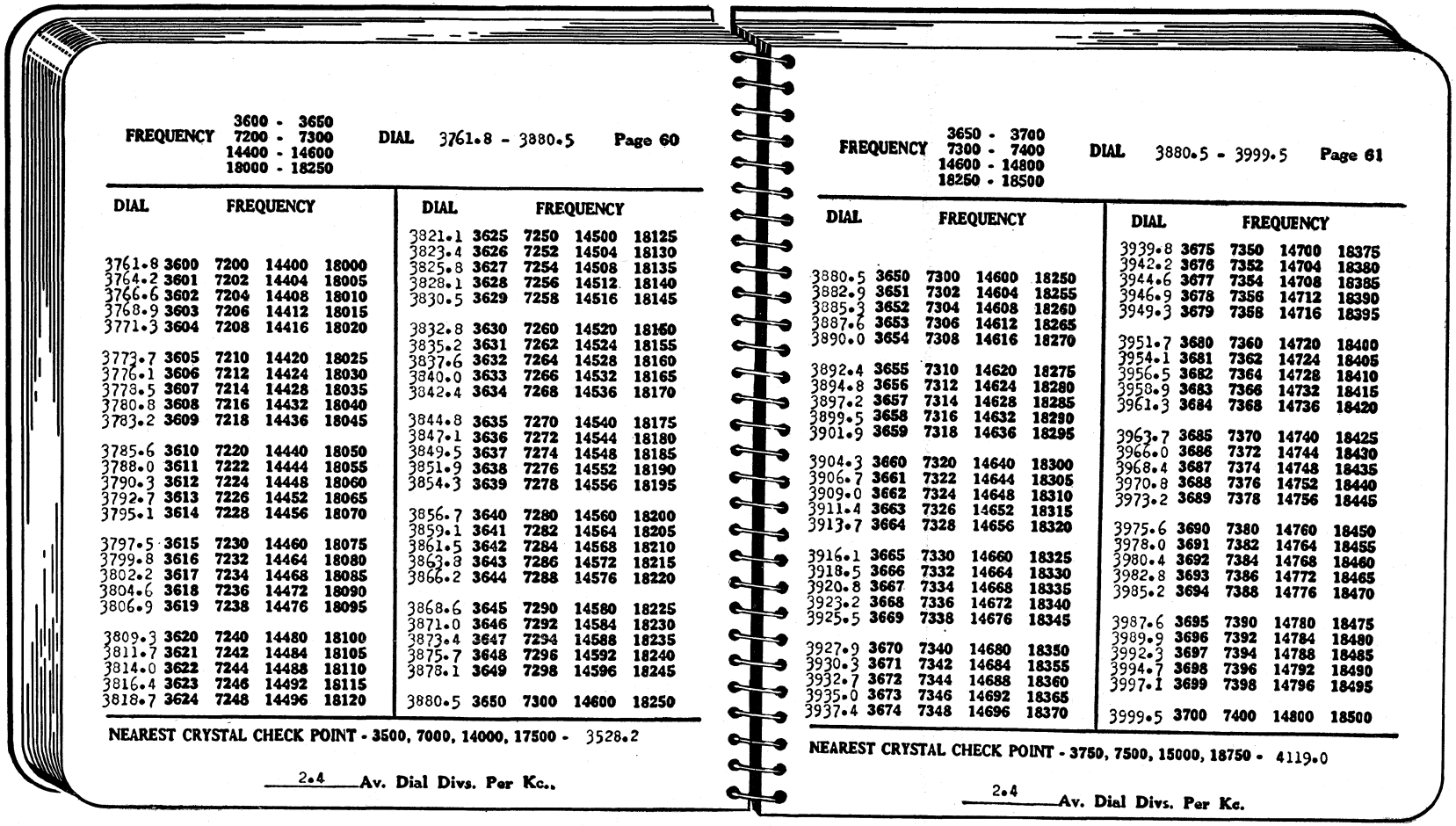
$$X = \frac{1.4}{2.4} = .583.$$

The unknown frequency is 3,649 minus .583, or 3648.417 kc. The last two significant figures can be discarded for all practical purposes.

f. USES. Frequency meters are used to check unknown frequencies and also to check or set the frequency of a receiver or a transmitter. To tune a transmitter to a desired frequency, find the page in the calibration book that shows the dial setting of the frequency to which the transmitter is to be tuned; with the crystal oscillator turned on, the frequency-meter dial then is set to the *nearest* crystal check point. The CORRECTOR control then is adjusted to obtain zero beat in the headphones, the crystal oscillator is turned off, and the frequency-meter dial is set to the desired frequency. The transmitter then is loosely coupled to the frequency meter and tuned until zero beat is obtained. An identical procedure is used when tuning a receiver or other equipment.

72. Secondary Frequency Standard

a. INTRODUCTION. The output frequency of the crystal oscillator used to calibrate a heterodyne frequency meter is called a standard frequency. It is a reference frequency with which the output of the variable oscillator is compared. Some equipments do not contain a crystal calibration oscillator within their units and another method of obtaining a standard frequency must be used. There are two methods of obtaining this frequency standard. The *primary* frequency standard uses radio signals sent out by a permanent transmitter, such as Station WWV at Arlington, Virginia. These signals are used as the standard frequencies for calibration of equipment and take the place of the crystal oscillator in a heterodyne frequency meter. The more common method is to use the crystal oscillator in a heterodyne frequency meter as a *secondary* frequency standard. This secondary frequency standard can be used to check the accuracy of any oscillator within its frequency



FREQUENCY 3600 - 3650, 7200 - 7300, 14400 - 14600, 18000 - 18250 DIAL 3761.8 - 3880.5 Page 60

DIAL	FREQUENCY			
3761.8	3600	7200	14400	18000
3764.2	3601	7202	14404	18005
3766.6	3602	7204	14408	18010
3768.9	3603	7206	14412	18015
3771.3	3604	7208	14416	18020
3773.7	3605	7210	14420	18025
3776.1	3606	7212	14424	18030
3778.5	3607	7214	14428	18035
3780.8	3608	7216	14432	18040
3783.2	3609	7218	14436	18045
3785.6	3610	7220	14440	18050
3788.0	3611	7222	14444	18055
3790.3	3612	7224	14448	18060
3792.7	3613	7226	14452	18065
3795.1	3614	7228	14456	18070
3797.5	3615	7230	14460	18075
3799.8	3616	7232	14464	18080
3802.2	3617	7234	14468	18085
3804.6	3618	7236	14472	18090
3806.9	3619	7238	14476	18095
3809.3	3620	7240	14480	18100
3811.7	3621	7242	14484	18105
3814.0	3622	7244	14488	18110
3816.4	3623	7246	14492	18115
3818.7	3624	7248	14496	18120
3821.1	3625	7250	14500	18125
3823.4	3626	7252	14504	18130
3825.8	3627	7254	14508	18135
3828.1	3628	7256	14512	18140
3830.5	3629	7258	14516	18145
3832.8	3630	7260	14520	18150
3835.2	3631	7262	14524	18155
3837.6	3632	7264	14528	18160
3840.0	3633	7266	14532	18165
3842.4	3634	7268	14536	18170
3844.8	3635	7270	14540	18175
3847.1	3636	7272	14544	18180
3849.5	3637	7274	14548	18185
3851.9	3638	7276	14552	18190
3854.3	3639	7278	14556	18195
3856.7	3640	7280	14560	18200
3859.1	3641	7282	14564	18205
3861.5	3642	7284	14568	18210
3863.8	3643	7286	14572	18215
3866.2	3644	7288	14576	18220
3868.6	3645	7290	14580	18225
3871.0	3646	7292	14584	18230
3873.4	3647	7294	14588	18235
3875.7	3648	7296	14592	18240
3878.1	3649	7298	14596	18245
3880.5	3650	7300	14600	18250

NEAREST CRYSTAL CHECK POINT - 3500, 7000, 14000, 17500 - 3528.2

2.4 Av. Dial Divs. Per Kc.

FREQUENCY 3650 - 3700, 7300 - 7400, 14600 - 14800, 18250 - 18500 DIAL 3880.5 - 3999.5 Page 61

DIAL	FREQUENCY			
3880.5	3650	7300	14600	18250
3882.9	3651	7302	14604	18255
3885.3	3652	7304	14608	18260
3887.6	3653	7306	14612	18265
3890.0	3654	7308	14616	18270
3892.4	3655	7310	14620	18275
3894.8	3656	7312	14624	18280
3897.2	3657	7314	14628	18285
3899.5	3658	7316	14632	18290
3901.9	3659	7318	14636	18295
3904.3	3660	7320	14640	18300
3906.7	3661	7322	14644	18305
3909.0	3662	7324	14648	18310
3911.4	3663	7326	14652	18315
3913.7	3664	7328	14656	18320
3916.1	3665	7330	14660	18325
3918.5	3666	7332	14664	18330
3920.8	3667	7334	14668	18335
3923.2	3668	7336	14672	18340
3925.5	3669	7338	14676	18345
3927.9	3670	7340	14680	18350
3930.3	3671	7342	14684	18355
3932.7	3672	7344	14688	18360
3935.0	3673	7346	14692	18365
3937.4	3674	7348	14696	18370
3939.8	3675	7350	14700	18375
3942.2	3676	7352	14704	18380
3944.6	3677	7354	14708	18385
3946.9	3678	7356	14712	18390
3949.3	3679	7358	14716	18395
3951.7	3680	7360	14720	18400
3954.1	3681	7362	14724	18405
3956.5	3682	7364	14728	18410
3958.9	3683	7366	14732	18415
3961.3	3684	7368	14736	18420
3963.7	3685	7370	14740	18425
3966.0	3686	7372	14744	18430
3968.4	3687	7374	14748	18435
3970.8	3688	7376	14752	18440
3973.2	3689	7378	14756	18445
3975.6	3690	7380	14760	18450
3978.0	3691	7382	14764	18455
3980.4	3692	7384	14768	18460
3982.8	3693	7386	14772	18465
3985.2	3694	7388	14776	18470
3987.6	3695	7390	14780	18475
3989.9	3696	7392	14784	18480
3992.3	3697	7394	14788	18485
3994.7	3698	7396	14792	18490
3997.1	3699	7398	14796	18495
3999.5	3700	7400	14800	18500

NEAREST CRYSTAL CHECK POINT - 3750, 7500, 15000, 18750 - 4119.0

2.4 Av. Dial Divs. Per Kc.

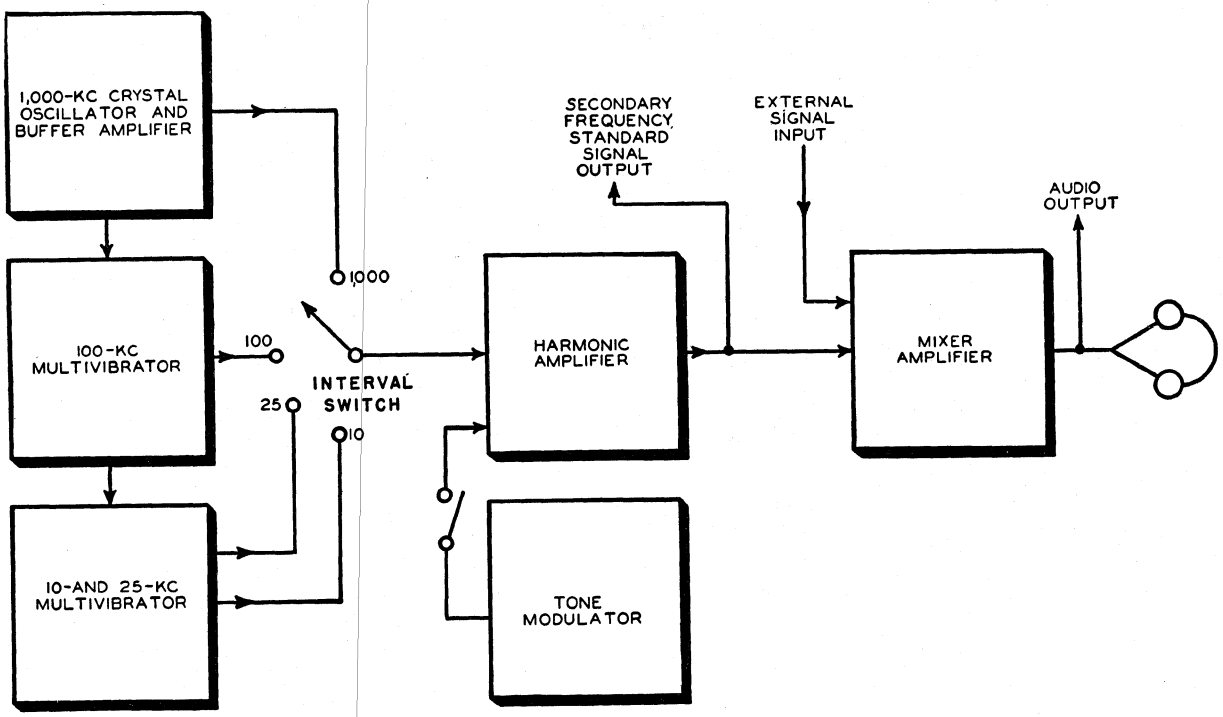
TM 664-97

Figure 97. Two pages of typical calibration book.

range and does not require a separate piece of equipment for calibration purposes.

b. BLOCK DIAGRAM. A block diagram of a secondary frequency standard is shown in figure 98. When the INTERVAL switch is in the 1,000-kc position, the 1,000-kc crystal oscillator and buffer amplifier feed the harmonic amplifier. The harmonic amplifier is used to amplify the harmonics fed from the 1,000-kc oscillator and the 100-, 25- and 10-kc multivibrators. The output of the harmonic amplifier then beats against the external signal input in the mixer amplifier. If the difference frequency is in the audio range, it is heard in the headphones. If the frequency of the external signal input equals the fundamental frequency, or a harmonic of the 1,000-kc crystal oscillator, no sound is heard in the headphones. For example, if the external frequency is 2,000 kc, the second harmonic of the oscillator will beat with it, and because the difference frequency is zero no ouput will appear in the headphones. However, if the signal is 2,010 kc or 1,090 kc, there is a 10-kc difference between the two frequencies and a high-pitched 10,000-cycle beat note will appear in the headphones. When the signal is 2,020 kc or 1,080 kc, the difference frequency is 20,000 cycles and the signal again cannot be heard in the headphones because it is above the audible range. As the difference frequency approaches the audible range, a high-frequency beat note is heard that gradually decreases in frequency until the zero-beat frequency is reached. If the signal is tuned past the zero-beat frequency, a low-frequency note appears that gradually increases in pitch until the audible range of frequencies is past, and the signal is no longer heard in the headphones. When the INTERVAL switch is in the 100-kc position, a 100-kc multivibrator feeds the harmonic amplifier. On the 25- and 10-kc positions, a 10- and 25-kc multivibrator feeds the harmonic amplifier. The multivibrators produce signals at 100-, 10-, and 25-kc intervals to extend the range of the secondary frequency standard, and are synchronized by the 1,000-kc crystal oscillator. The tone modulator is an audio-frequency oscillator that can be connected to the harmonic amplifier by a switch when a modulated signal is required at the output.

c. FRONT VIEW OF SECONDARY FREQUENCY STANDARD.



TM 664-98

Figure 98. Block diagram of typical secondary frequency standard.

(1) The INTERVAL switch, located on the right side of the secondary frequency standard panel (fig. 98), is used to select the low-frequency oscillator harmonic output at the desired intervals. The ZERO SET adjustment varies the 1,000-kc crystal oscillator frequency a few cycles in either direction to compensate for temperature changes. Ordinarily, it is used only when checking the secondary frequency standard against a primary frequency standard. The BAND switch located at the lower left corner of the panel permits selection of any one of six frequency bands. The total frequency coverage of this secondary standard is from 10 kc to 50 mc.

(2) The AMP TUNE control (lower center of panel) is used to adjust the output level of the harmonic amplifier. There are three switches at the bottom of the panel. The FIL switch turns on all the filaments and the pilot light. The PLATE switch applies the plate voltage to all tubes. The MOD switch makes a 900-cps note available when a modulated signal is required. The GAIN controls the level of r-f output of the secondary standard as well as the volume of the beat-frequency output available at the PHONE jack. It also controls the level of the r-f input signal applied to the mixer amplifier through the INPUT terminals.

d. USES. The secondary frequency standard is used to determine an unknown frequency or to calibrate a transmitter or receiver. The secondary frequency standard is used also to calibrate wavemeters, signal generators, oscilloscopes, and heterodyne frequency meters

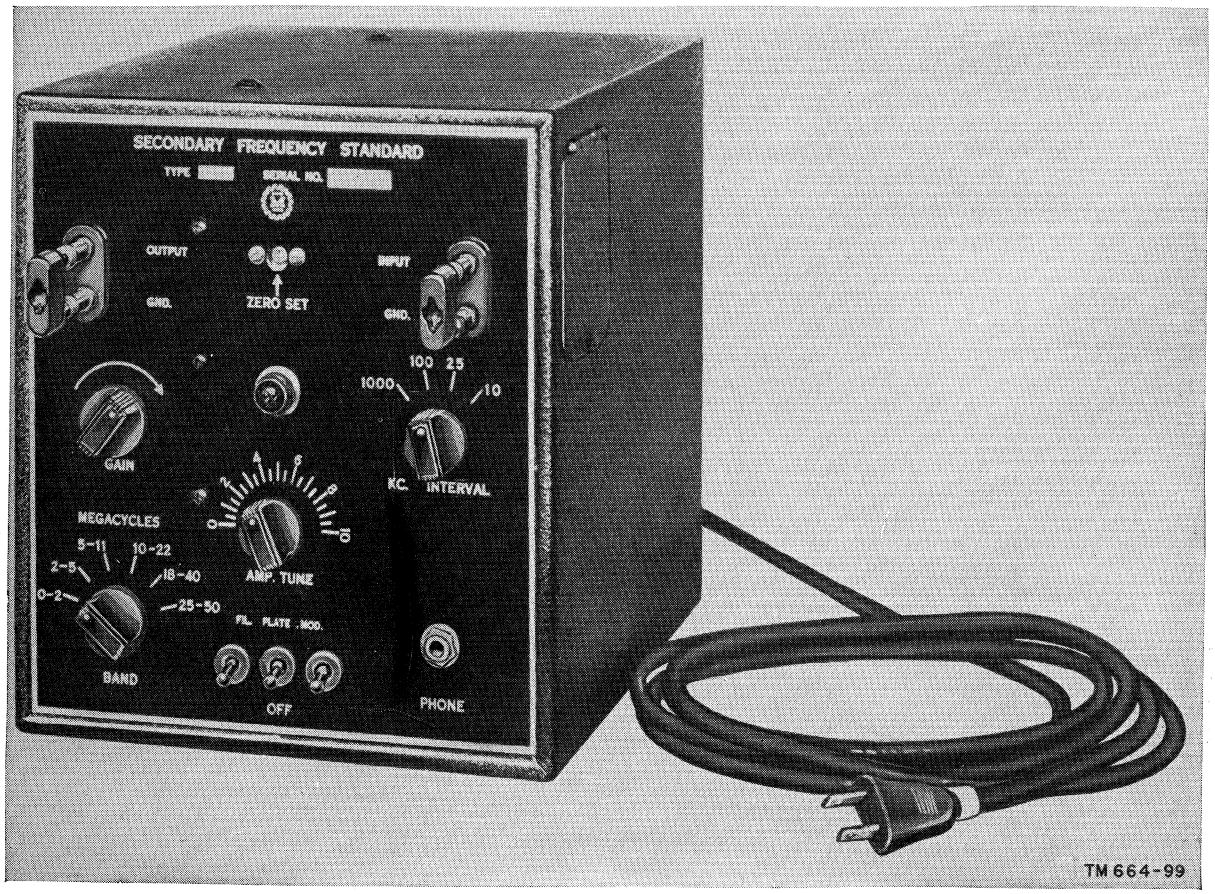


Figure 99. Typical secondary frequency standard.

which do not contain a calibrated crystal oscillator.

73. Summary

a. A *wavemeter* is a frequency meter which contains a variable tuned circuit whose resonant frequency is made to equal the unknown frequency.

b. A reaction wavemeter absorbs very little power from the equipment whose frequency is to be measured. An indicating device (usually an ammeter) is located in the circuit whose frequency is to be measured.

c. An *absorption* wavemeter absorbs a small quantity of power from the equipment whose frequency is to be measured. An indicating device, such as an ammeter, a lamp, or an earphone in the wavemeter, is used to indicate the unknown frequency.

d. Loose coupling is ideal for frequency measurements, since the indication at resonance is very sharp.

e. A micrometer consists of a thimble containing a vernier scale which is rotated about a barrel containing a coarse scale.

f. A *heterodyne,* or *beat,* frequency meter generates signals of known frequencies and compares them with an unknown frequency.

g. In a heterodyne frequency meter, when the known and unknown frequencies are equal a *zero-beat* frequency results.

h. The points at which the variable oscillator in a heterodyne frequency meter can be calibrated with a crystal oscillator are known as *crystal check points.*

i. The frequency corresponding to the dial setting on a frequency meter is obtained in a *calibration* book or chart.

j. When calibrating an oscillator by the primary frequency standard method, radio signals sent out by a permanent transmitter at specific frequencies are used as the calibration points.

k. When calibrating an oscillator by the secondary frequency standard method, a separate piece of equipment is used to transmit specific frequencies which are used as the calibration points.

l. A secondary frequency standard is used to determine an unknown frequency or to calibrate a transmitter or receiver which does not contain a crystal oscillator.

74. Review Questions

a. Give two uses of a frequency meter.

b. Explain the difference between an absorption wavemeter and a reaction wavemeter.

c. How does coupling affect the operation of a reaction wavemeter?

d. Why is loose coupling desirable in frequency measurements?

e. Draw a block diagram of an absorption wavemeter using headphones as an indicating device.

f. Explain how an unknown frequency is determined by means of a reaction wavemeter.

g. What is meant by a zero-beat frequency?

h. Explain the basic principle of operation of a heterodyne frequency meter.

i. What are crystal check points?

j. What is a primary frequency standard?

k. What is a secondary frequency standard?

l. Why is a secondary frequency standard used?

SECTION XI

BRIDGES

75. Introduction

A bridge is a sensitive device used to measure resistance, capacitance, or inductance when great accuracy of measurement is desired. The bridges can be used also for measuring reactance, impedance, and frequency. All bridge circuits include a source of a-c or d-c voltage; an indicating device, usually a sensitive galvanometer or headphones; an adjustable standard, usually a resistor or capacitor; the unknown whose value is to be measured; and a method of determining how much the unknown value differs from the standard.

76. Wheatstone Bridge

a. The most common type of bridge used is the *Wheatstone* bridge (fig. 100). The bridge shown is known as the *diamond* arrangement, because the four resistors are shown schematically in the form of a diamond. Resistor R_x is the unknown resistor, R_a and R_b are known as *ratio arms,* and R_s as the *standard arm* of the bridge. R_a and R_b are fixed resistors in the bridge that provide a specific ratio of R_a/R_b, and maximum accuracy and sensitivity result when this ratio is 1/1. With the unknown resistor, R_x, inserted in the bridge, rheostat R_s is adjusted until the galvanometer reads zero. When this occurs, the voltage drops across R_a and R_b equal the voltage drops across R_s and R_x. In A, where R_a equals R_b, the ohmic value of R_s (450 ohms) must equal that of R_x for this condition to exist.

b. In B, a slightly different condition exists and the ratio of R_a/R_b is made equal to 200/600 or 1/3. To balance the bridge so that the galvanometer reads zero, the ratio of R_s/R_x must also be 1/3. Since R_s equals 150 ohms, then R_x must equal 450 ohms. This line of reasoning, when put in mathematical form, is shown by the formula,

$$\frac{R_a}{R_b} = \frac{R_s}{R_x}$$

Transposing this equation,

$$R_x = \frac{R_s \times R_b}{R_a} = \frac{150 \times 600}{200} = 450 \text{ ohms.}$$

c. Another Wheatstone bridge circuit, known as a slide-wire bridge, is shown in figure 101. A slide wire, made of a material such as manganin and consisting of a single wire divided in 100 equal parts, forms the ratio arm of the bridge. A contact point that can be moved manually along the wire is provided; the re-

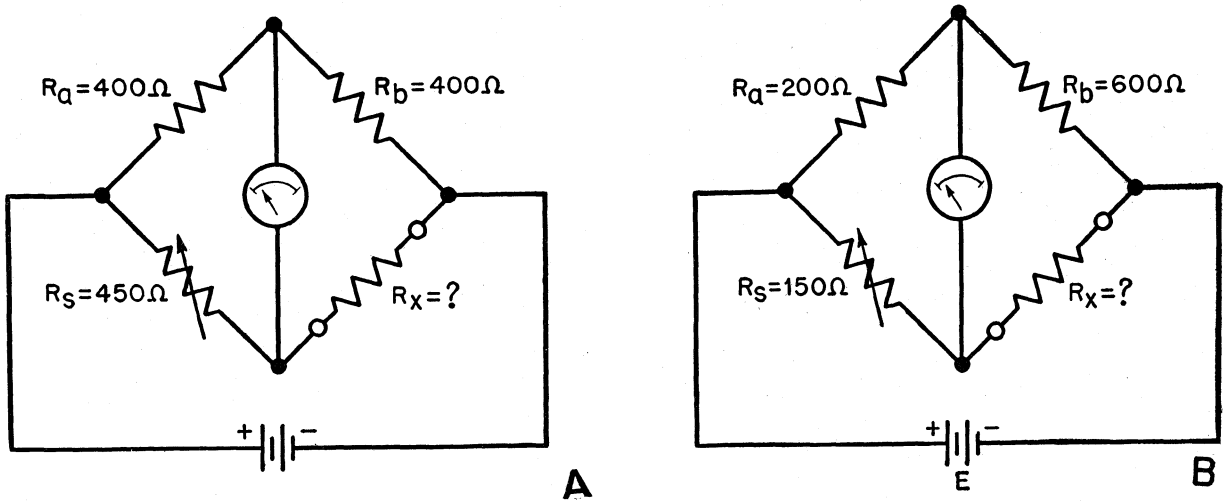


Figure 100. Determining an unknown resistance using diamond arrangement of Wheatstone bridge. TM 664-100

sistance to the left of the contact point represents R_a and that to the right represents resistor R_b. Moving the manually operated contact point along the slide wire varies the R_a/R_b ratio. The standard resistor, R_s, has four steps of 1, 10, 100, or 1,000 ohms, making it possible for the bridge to measure different ranges of resistance. An example of the method used to find the value of an unknown resistor can be shown by setting selector switch S to place 10 ohms in the arm. With the contact point in the position shown, scale A gives the value of R_a as 40 ohms, and scale B gives the value of R_b or 60 ohms. The unknown resistor, R_x, then can be found by the formula

$$R_x = \frac{R_s \times R_b}{R_a} = \frac{10 \times 60}{40} = 15 \text{ ohms.}$$

Nonuniformity of the resistance of the slide wire makes this type of bridge less accurate than the diamond arrangement.

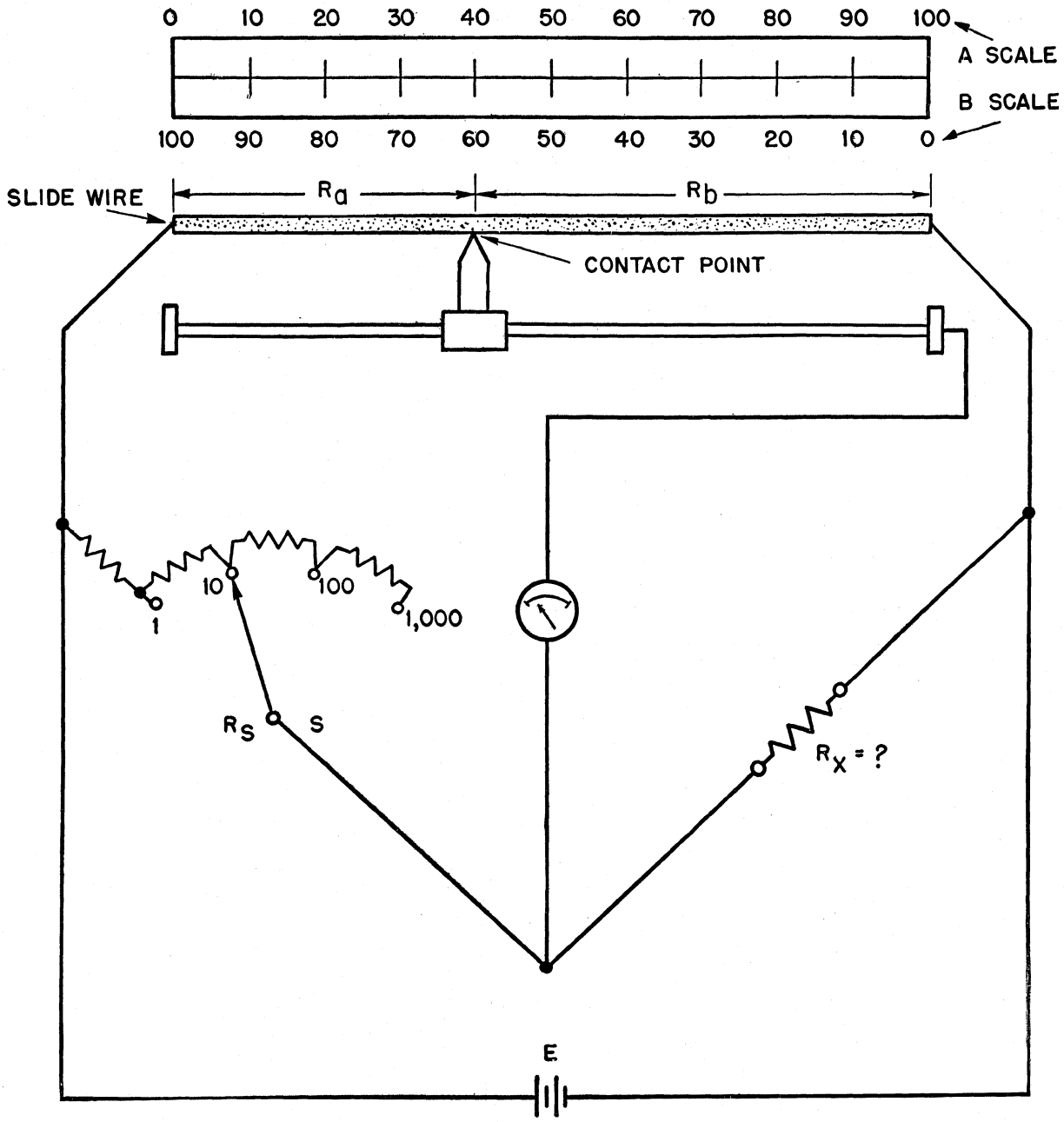


Figure 101. Determining an unknown resistance using slide-wire bridge. TM 564-101

77. Measuring Capacitance with a Bridge

a. When measuring an unknown capacitance on a bridge, an a-c source of voltage must be used. This is necessary because the reactance of the unknown capacitor is used to determine its capacitive value. Some typical methods of determining an unknown capacitance are given in figure 102. In the *series-resistance* capacitive bridge, in A, an a-c generator replaces the battery used in resistance measurements. Headphones are used as null indicators instead of a galvanometer, since their pick-up response is dependent on the reactance presented by the unknown capacitance. The ratio arms consist of R_a and R_b, with R_a adjustable so that the R_a/R_b ratio can be varied. In the standard arm, a calibrated variable capacitor, C_s, is in series with an adjustable resistor R_s. Capacitor C_x is the unknown capacitance, and R_{cx} represents the leakage resistance of the capacitor. When the bridge is balanced, the voltage drops across R_a, C_s, and R_s equal those across R_b, C_x, and R_{cx}. R_a is adjusted to give a specific R_a/R_b ratio, R_s is adjusted to compensate for the effects of R_{cx}, and C_s is adjusted to equal C_x. R_s and C_s are varied alternately until a zero beat is obtained in the headphones. The dial setting of C_s represents the unknown capacitance. The unknown capacitance can be computed mathematically by the relationship

$$C_x = C_s \times \frac{R_a}{R_b}.$$

b. Another method of determining the unknown capacitance, C_x, is illustrated in B. This is known as the *Schering* type of capacitance bridge. The distinguishing feature of this bridge is that the leakage resistance, R_{cx}, of the unknown capacitor is compensated for by the adjustable capacitor, C_a, which is in parallel with R_a. The fixed ratio arm, R_a, and the adjustable ratio arm, R_b, are connected across the headphones. C_a and the standard calibrated capacitor, C_s, are tuned until a zero beat is obtained in the headphones.

c. The capacitance of *electrolytic* capacitors, also, can be determined by using a capacitance bridge. However, a polarizing voltage supplied by a battery must be applied to the electrolytic capacitor, as shown in C. Capacitor C_r must be large enough that its reactance at the frequency of the a-c generator is a minimum so that the a-c voltage will be bypassed around the battery. The operation of this type of bridge arrangement is the same as the operation of other types of capacitance bridges.

d. When an unknown capacitance is small in value and great accuracy is desired, a *substitution* method is used commonly to determine its value. In this method, the resistors comprising the two ratio arms are made equal in value, and a known capacitor is connected across the terminals that are used to measure the unknown capacitor. The bridge then is balanced by adjusting the standard capacitor, and the reading of the dial setting is noted. The unknown capacitor is connected in parallel with the known

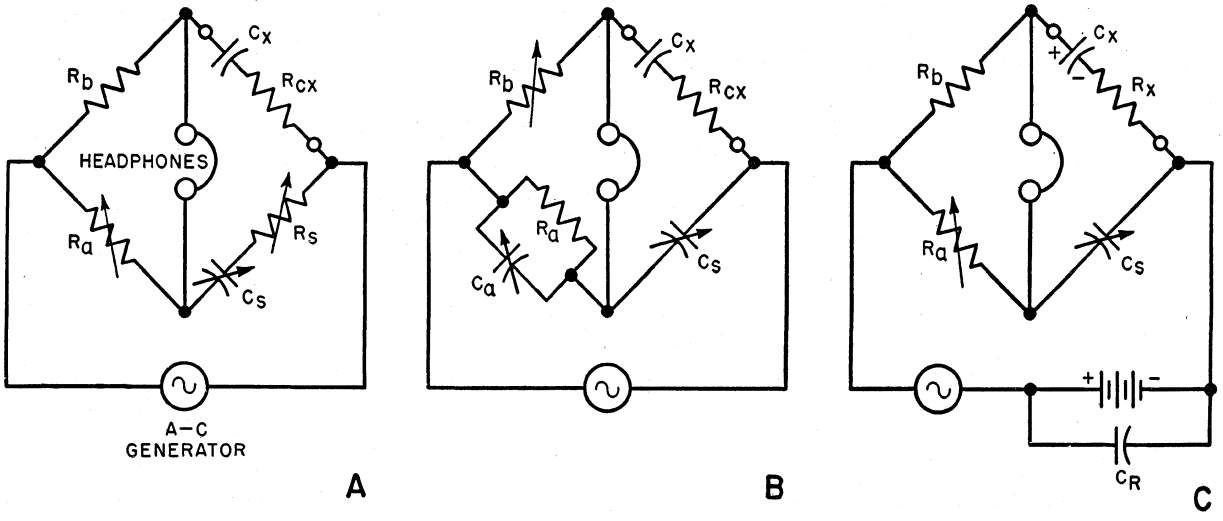


Figure 102. Typical bridge circuits for determining an unknown capacitance.

capacitor, and the bridge is balanced once more by adjusting the standard capacitor. The new reading of the dial setting is noted. The *difference* in the two readings is equal to the capacitance of the unknown.

e. The dissipation factor is the ratio of the resistance of a capacitor to its reactance and is a direct check of the capacitors quality. It is equal to

$$D = \frac{R_{cx}}{X_{cx}}, \text{ or } R_{cx} \times 2\pi f c_x$$

where D is the dissipation factor, R_{cx} is the leakage resistance, and X_{cx} the capacitive reactance of the capacitor. The greater the leakage resistance, the greater the dissipation factor, and when the capacitor has a higher dissipation factor than the value specified by the manufacturer, the capacitor should be discarded. In many capacitance bridges, provisions are made to measure the *dissipation factor* of a capacitor, and many equipments have dials on which it is indicated directly.

78. Measuring Inductance with a Bridge

a. An unknown inductance can be determined by using the Maxwell bridge shown in A of figure 103. R_a and R_b are the ratio arms, and both are adjustable to obtain various R_a/R_b ratios. I_x represents the unknown inductance and R_x the resistance of the inductor. The standard resistance, R_s, is adjusted to cancel the effects of R_x, the standard inductance, and L_s is adjusted to balance the bridge and obtain zero beat in the headphones. The inductance of L_s as read on a calibrated dial equals that of the unknown inductance. The unknown inductance also can be computed by the relationship

$$L_x = \frac{L_s \times R_b}{R_s}.$$

b. Since it is difficult to calibrate accurately a standard variable inductor, variable capacitors often are used as the standard instead of inductors. One type of bridge using a capacitor as its standard (B, fig. 103) is a variation of the Maxwell bridge. The standard capacitor, C_s, is adjusted to obtain the proper voltage drops around the circuit, and R_s is adjusted to cancel the effects of R_x. The ratio arms, R_a and R_b, are used to help balance the bridge and are connected to opposite sides of L_x. Dials on the equipment are read to determine directly the inductive value of L_x in henrys, millihenrys, or microhenrys. Inductance also can be directly computed from the relationship

$$L_x = C_s \times R_a \times R_b.$$

c. Another bridge used for inductance measurements, known as an Owen bridge, is shown in A of figure 104. As in the Maxwell bridge, L_x is located opposite the standard capacitor, C_s, so that a comparison can be made between C_s and L_x. A fixed capacitor or a series of capacitors which are switched into the arm, one at a time, can be used to replace C_s. The variable capacitor, C_a, is used to balance out R_x, and R_a and R_b balance the bridge. The mathematical relationship used for determining the unknown

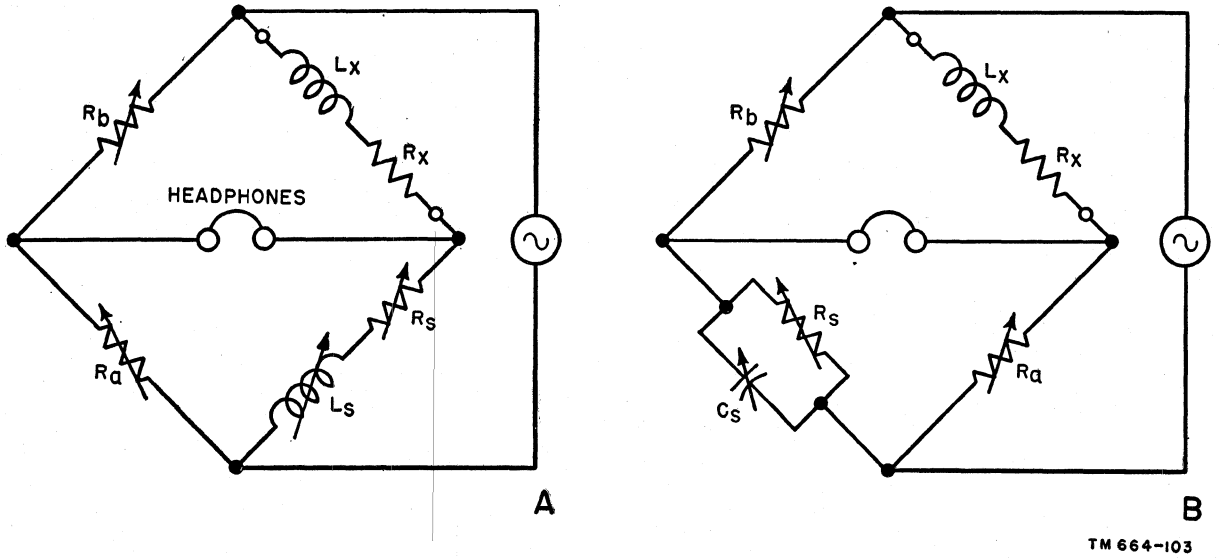


Figure 103. Methods for determining an unknown inductance, using a bridge circuit.

inductance in the Owen bridge is identical to that of the Maxwell bridge. Figure 104 shows the similarity between the Hay bridge and the Owen bridge. The standard capacitor, C_s, located opposite the unknown inductance, L_x, is in series with R_s. R_x is balanced by R_s, L_x is balanced by C_s, and the variable resistors, R_a and R_b, complete the balance of the bridge. This type generally is used for measuring inductances having a $Q(X_L/R)$ greater than 10.

d. Just as the dissipation factor is used to measure the quality of a capacitor, *storage factor* sometimes is used to measure the quality of an inductor. Storage factor is defined as the reciprocal of the dissipation factor and is equal to

$$S = \frac{X_L}{R_L}$$

where X_L is the inductive reactance of the coil and R_L the resistance of the inductor. This is identical to the Q (figure of merit) of a coil and it is desirable for an inductance to have a high storage factor.

79. Practical Impedance Bridge

a. SCHEMATIC DIAGRAM.

(1) The schematic of a practical impedance bridge used to measure resistance, capacitance, inductance, dissipation factor and storage factor is shown in figure 105. When measuring resistance, the unknown resistor is connected to the RES terminals. When measuring inductance or capacitance, the unknown reactor is connected to the L-C terminals. Switches S_2 *and* S_3 are ganged and when positioned as shown (R position), resistance can be measured. Switch S_1 determines the amount of resistance in the ratio arms. The resistors of S_1—A represent R_a and those of S_1—B represent R_b as used in previous bridge explanations.

(2) With S_2 and S_3 in the C position, inductance, dissipation factor, and storage factor can be measured. The L-C terminals are connected, and the RES terminal is disconnected from the bridge. The lower sections of S_2 and S_3 connect positions, D, DQ, and Q. When in the D position, the upper sections of S_2 and S_3 are in the C position and the dissipation factor can be measured. The DQ position is used when it is desired to measure storage factor where the Q of the coil is less than 10, and the Q position is used for values of Q greater than 10. When measuring capacitance or dissipation factor, R_{11}, R_{13}, and C_1 are included in the bridge circuit. R_{11} and R_{13} help balance the bridge, and C_1 is a d-c blocking capacitor. When measuring inductance or storage factor, R_{11}, R_{12}, and C_2 are included in the bridge cir-

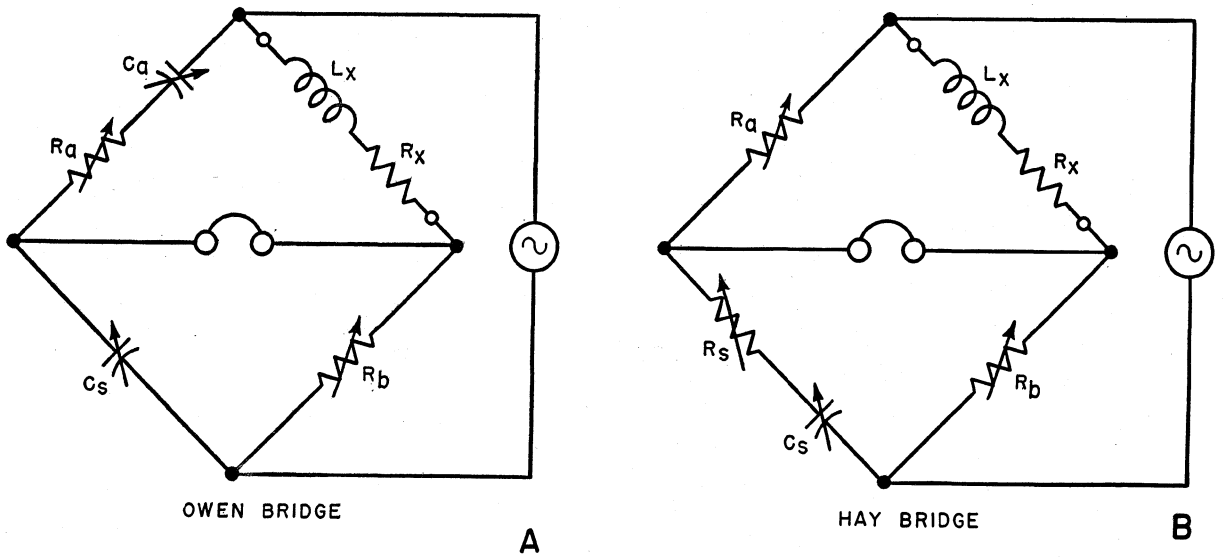


Figure 104. Owen and Hay bridges used for determining an unknown inductance.

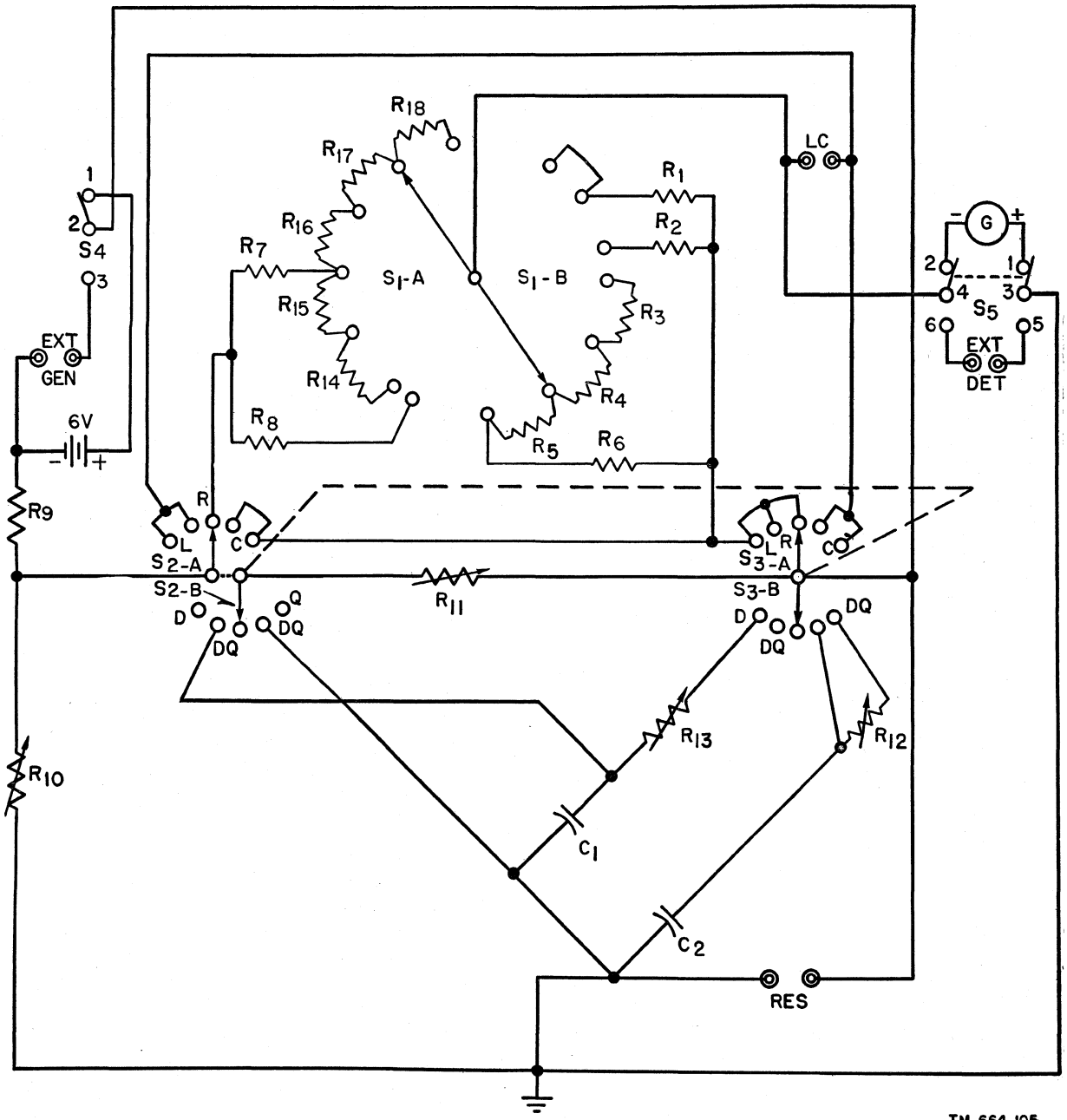


Figure 105. Schematic of typical practical impedance bridge.

TM 664-105

cuit. R_{11} is used to balance the bridge for a storage factor greater than 10, and R_{12} for a storage factor less than 10. C_2 is a d-c blocking capacitor.

(3) When resistance is being measured, switch S_5 is in the position shown, and the galvanometer is in the bridge circuit. When S_5 is in positions 5 and 6, headphones can be connected to the EXT DET terminals of the bridge circuit. S_5 remains in this position when measuring inductance or capacitance. When measuring resistance, with S_4 in the position shown, a 6-volt battery is inserted in the bridge circuit. When S_4 is thrown so that the EXT GEN terminals are connected to the bridge instead of the battery, an external a-c source, usually an audio oscillator, can be connected to the

bridge. This is the position in which inductance and capacitance are measured. Resistor R_9 is a current-limiting resistor for the external a-c generator.

b. CIRCUIT FOR MEASURING RESISTANCE. If the circuit of figure 105 is used to measure resistance, the conditions shown in the simplified diagram (fig. 106) exist. With switches S_2 and S_3 in the R positions and S_1—A as shown, the R_a ratio arm consists of R_7, R_{16}, and R_{17}. Switch S_1—B puts R_5 and R_6 in the ratio arm R_b. With S_5 in the position shown, the galvanometer also is in the bridge and the 6-volt battery is connected in the circuit. The unknown resistor, R_x, is inserted between the RES terminals, and the calibrated resistor, R_{10} (the standard) is adjusted to balance the bridge. The ohmic value of the unknown resistor is read on the panel of the bridge equipment. Its reading is dependent upon the ohmic values of the two ratio arms and R_{10}.

c. MAXWELL BRIDGE. The Maxwell bridge circuit arrangement of figure 105 can be used also to measure inductance and storage factor (fig. 107). With S_2 and S_3 in the L, DQ positions, headphones are connected to the EXT DET terminals, and an audio oscillator is connected to the EXT GEN terminals. The unknown inductor, L_x, then is connected to the L-C terminals and R_{10} and R_{11} are adjusted to balance the bridge (minimum indication in the headphones). Resistor R_x represents the d-c resistance of the unknown inductor. Inductance and storage factor are read directly from dials on the bridge equipment.

d. HAY BRIDGE. The circuit shown in figure 105 can be connected as a Hay bridge to measure inductance and storage factor (fig. 108). The Hay bridge is used to measure storage factors greater than 10. The arrangement of all the switches in the Hay bridge is the same as those for the Maxwell bridge with the exception of S_2 and S_3. These switches are arranged so that their lower sections are connected to the Q position, their upper sections remaining in the L position. Resistor R_{12} in series with capacitor C_1 is the standard arm of the bridge. The remainder of the Hay bridge is identical to the Maxwell bridge arrangement.

e. CIRCUIT FOR MEASURING CAPACITANCE. The circuit of figure 105 also can be arranged (fig. 109) to measure an unknown capacitor and dissipation factor. Switches S_2 and S_3 are arranged so that their upper sections are in the C position and their lower sections are in the D position. This causes C_1 to be in series with R_{13} in the standard arm. R_5 and R_6 become the R_b ratio arm. C_x represents the capacitance to be measured, and R_x the d-c resistance of the capacitor. The bridge is balanced by adjusting R_{10} and R_{13}. A minimum indication is heard in the headphones, and capacitance, or dissipation factor, is read directly on the panel of the bridge.

80. Summary

a. A bridge is a sensitive device which is used to measure an unknown resistance, capacitance, inductance, or reactance.

b. The most common bridge used to measure an unknown resistance is the Wheatstone bridge.

c. The mathematical relationship for determining an unknown resistance in a bridge circuit is

$$R_x = \frac{R_s \times R_b}{R_a}.$$

d. A slide-wire Wheatstone bridge uses a single piece of high-resistance wire as the R_a and R_b ratio arms.

e. When measuring an unknown capacitance, an a-c generator and headphones are used instead of a battery and galvanometer as in a Wheatstone bridge.

f. The mathematical relationship for determining an unknown capacitor in a bridge circuit is

$$C_x = C_s \times \frac{R_a}{R_b}.$$

g. Dissipation factor determines the leakage resistance of a capacitor and is equal to the leakage resistance divided by the reactance of the capacitor, or $R_{cx} \times 2\pi f c_x$.

h. Inductance bridges often use variable capacitors instead of variable inductors as the standard because they are easier to calibrate.

i. The mathematical relationship for determining an unknown inductor in a bridge circuit is

$$L_x = C_s \times R_a \times R_b.$$

j. Storage factor determines the worth of an inductor and is equal to its reactance divided by its d-c resistance.

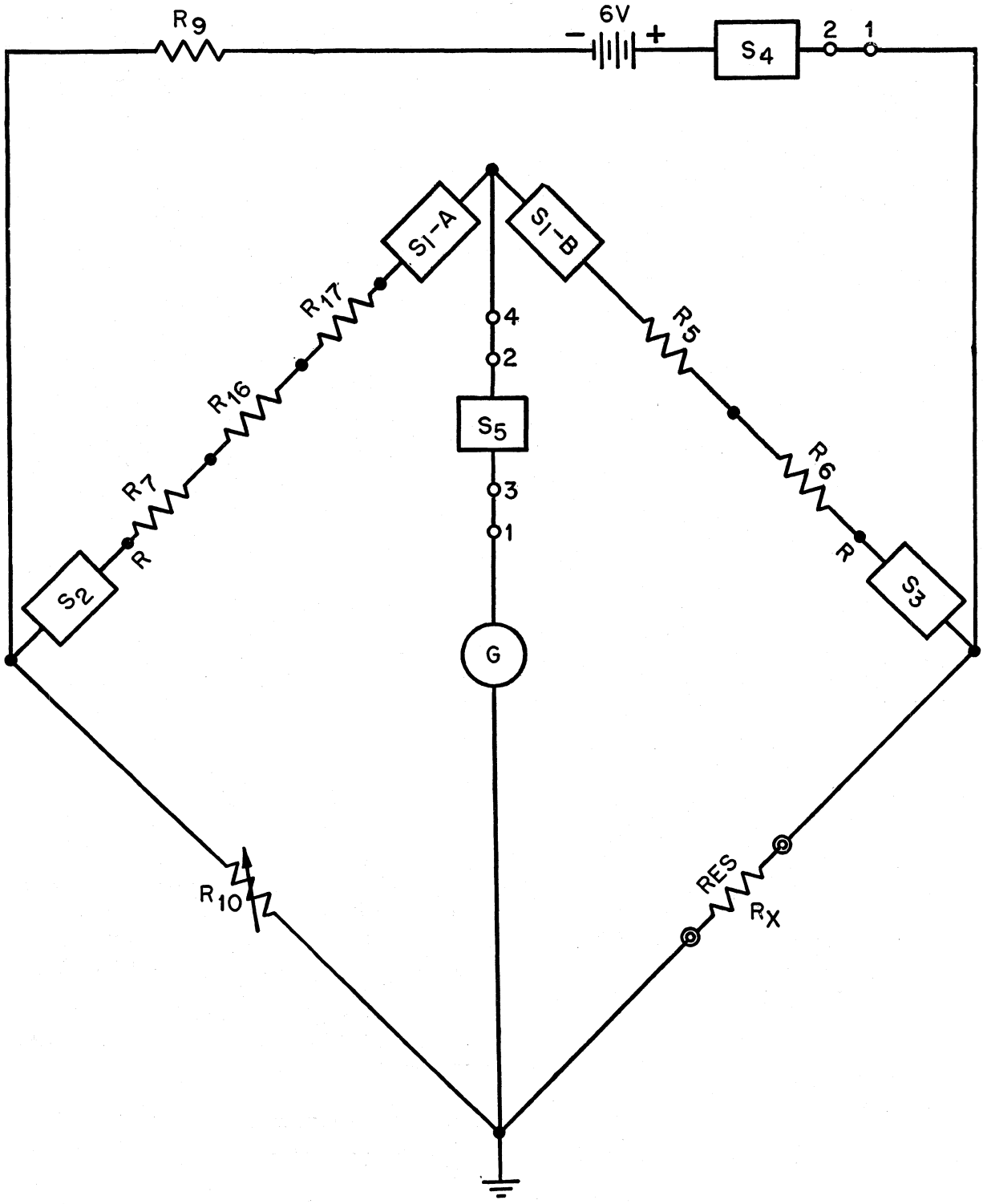


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Figure 106. Circuit for measuring resistance.

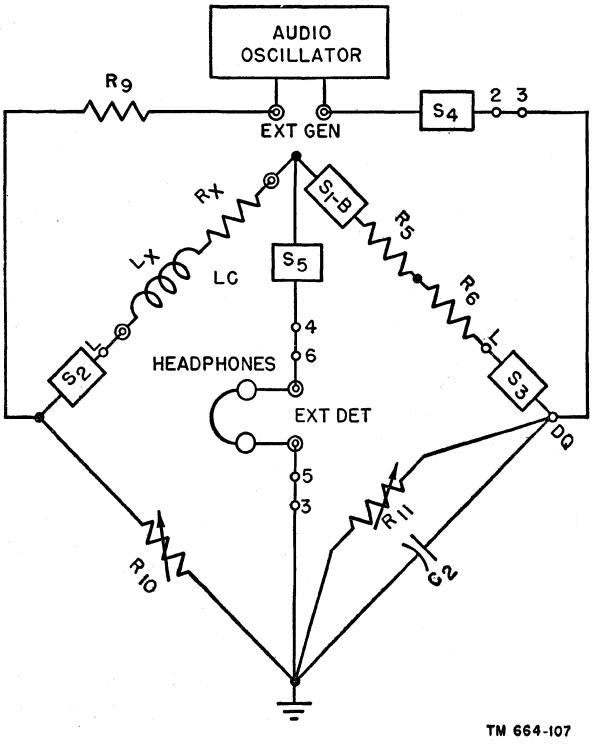

Figure 107. Maxwell bridge circuit for measuring inductance and storage factor.

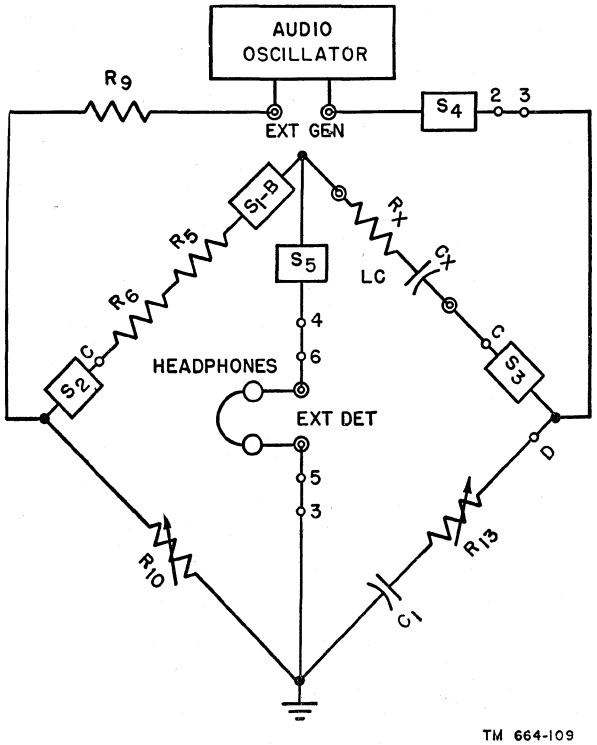

Figure 109. Circuit for measuring capacitance and dissipation factor.

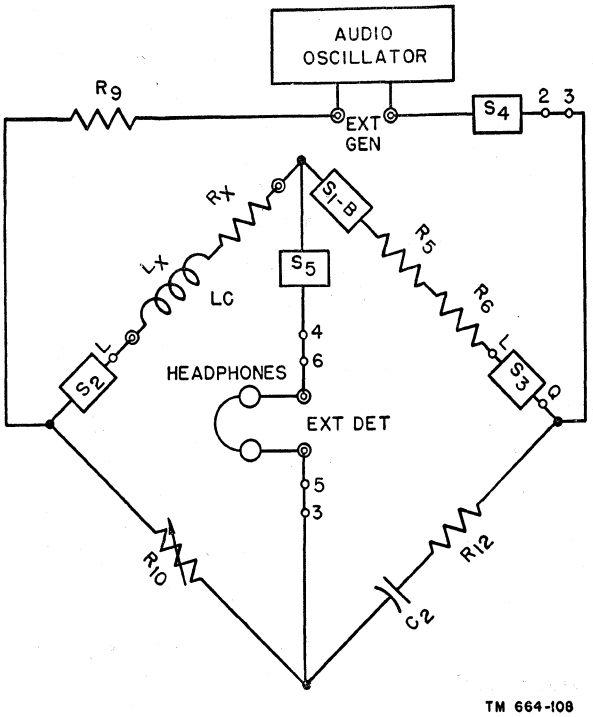

Figure 108. Hay bridge circuit for measuring inductance and storage factor.

81. Review Questions

a. Define a bridge circuit.

b. Can a Wheatstone bridge be used to measure an unknown reactance?

c. Why is it desirable to have the R_b/R_a ratio in a Wheatstone bridge equal to 1?

d. What is the distinguishing characteristic of a slide-wire type Wheatstone bridge?

e. Why are a-c generators and headphones used in reactive bridge circuits instead of batteries and galvanometers?

f. What changes must be made in a capacitive bridge circuit when measuring an electrolytic capacitor?

g. Explain the difference between dissipation factor and storage factor.

h. If capacitive bridges use capacitors as the standard, then why do not inductive bridges use inductors as the standard?

i. What are the mathematical relationships for determining an unknown resistor, capacitor, and inductor in a bridge circuit?

j. What is a storage factor?

SECTION XII

MISCELLANEOUS TEST EQUIPMENT

82. Hydrometer

a. General Description and Use. The hydrometer consists of a glass tube several inches long with a glass bulb filled with mercury or shot at one end. This permits the hydrometer to float in an upright position when placed in the liquid electrolyte (fig. 110). A scale calibrated in values of specific gravity is etched on the hydrometer stem. Frequently, the decimal point is omitted from this scale and a specific gravity of 1.265 or 1.325 will appear as 1265 or 1365. The hydrometer is used to measure the specific gravity of a liquid, such as the electrolyte in a storage battery. The condition of charge of a lead-acid storage battery can be determined accurately by knowing the specific gravity of its liquid electrolyte. The specific gravity of a liquid is a ratio which compares the weight of a certain volume of the liquid with the weight of the same volume of pure water. For example, if a liquid has a specific gravity of 1.265 then a certain volume of this liquid weighs 1.265 times as much as an equal volume of water. It can be said also that the density is 1.265 times that of water.

b. Functioning of Parts.

(1) The operation of the hydrometer is based on the principle that a floating object is in equilibrium under the action of two forces—its weight and a buoyant force equal to the weight of the liquid displaced. The hydrometer has a certain definite mass; when it is floated in a liquid, it sinks until it displaces its own weight. If the liquid is very dense (high specific gravity), the hydrometer does not sink far and a small amount of liquid is displaced; if the liquid is not dense (low specific gravity), the hydrometer sinks far down in the liquid.

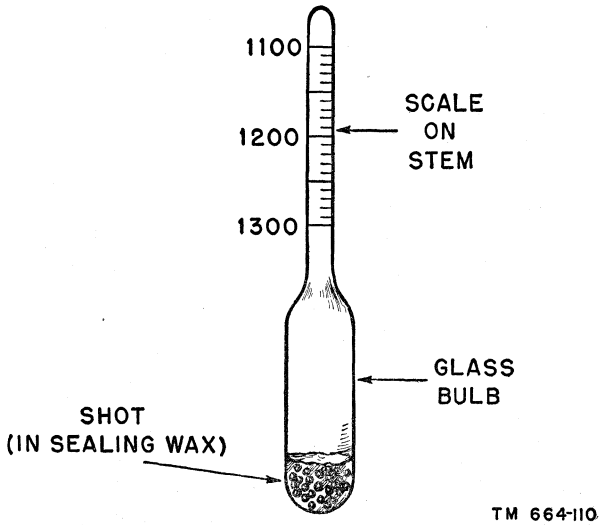

Figure 110. Hydrometer with shot for weight and calibrated scale.

(2) A calibrated scale is provided on the stem of the hydrometer to read the specific gravity directly at the point where the stem projects through the liquid surface. The topmost point on the scale indicates the lowest specific gravity reading because, with low-density liquids, the hydrometer is almost completely submerged. The lowest point on the scale indicates the highest specific gravity reading because, with high-density liquids, the hydrometer stem is almost completely exposed.

(3) The simple hydrometer described above is suitable for measuring the specific gravity of the electrolyte in a laboratory-type open-jar storage battery. Most storage batteries used in

military equipment, however, use closed hard-rubber containers. The top of the battery has a number of filling plugs which are screwed into small threaded openings in the battery cover. The level of the electrolyte usually is not more than one-half inch from the top of the battery plates. Therefore, a *hydrometer syringe* must be used to measure the electrolyte density of these batteries.

83. Hydrometer Syringe

a. PARTS. The hydrometer syringe consists of a large glass tube within which is the hydrometer, or float. A rubber bulb is attached to one end of the tube and a long rubber nozzle is attached to the other end (fig. 111). Frequently, the hydrometer syringe is referred to as a hydrometer. The term, however, should apply only to the float.

b. OPERATION.

(1) The rubber nozzle of the hydrometer syringe is inserted in the filling-plug hole of the storage battery and some of the electrolyte is withdrawn by means of the rubber bulb so that the hydrometer floats freely. The body of the syringe should be held vertically so that the hydrometer does not touch the side wall of the tube. The specific gravity of the cell being tested then is read on the calibrated scale on the stem of the hydrometer. The reading is taken as that value on the scale just at the surface of the liquid electrolyte. It is important to keep the nozzle of the hydrometer syringe in the cell being tested. If the hydrometer syringe is lifted from the cell, some of the acid electrolyte falling on clothing, skin, or unprotected metals and wood can

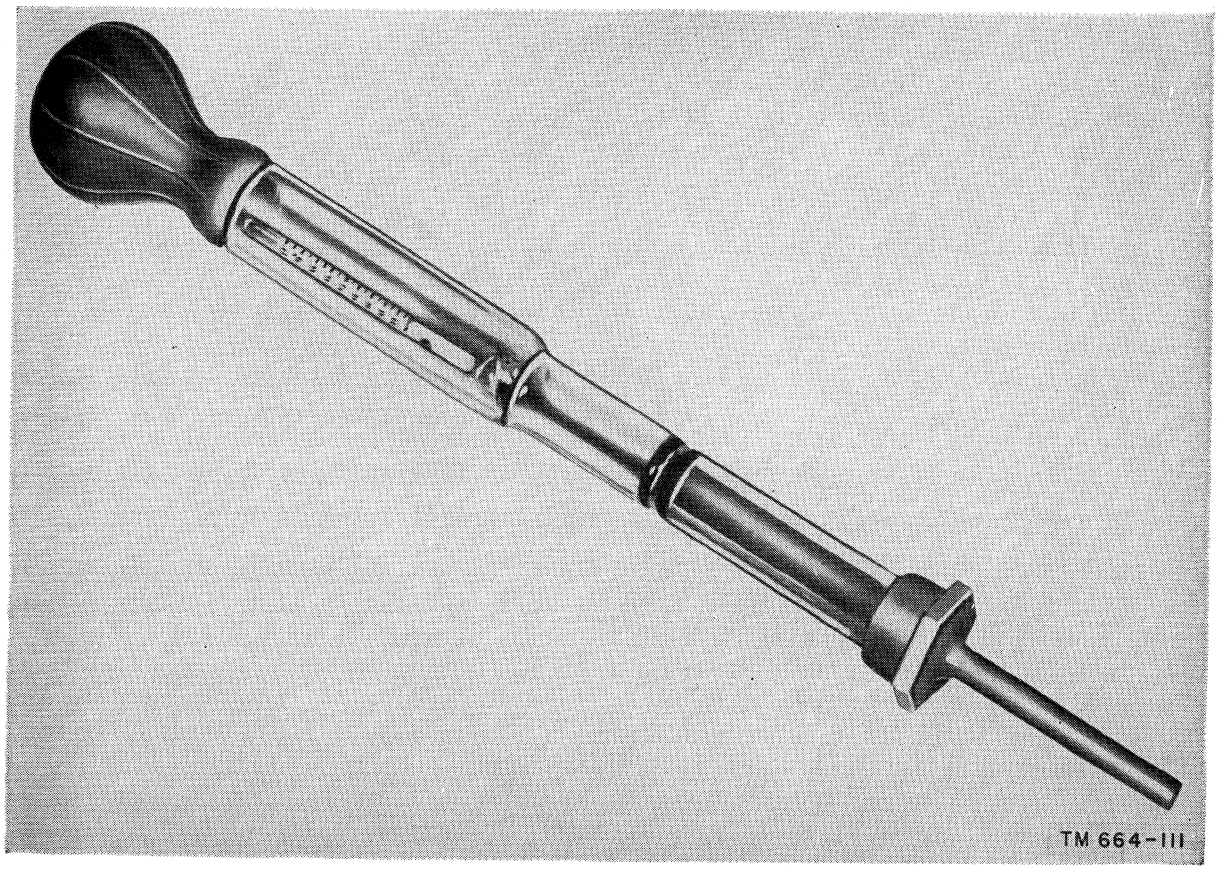

Figure 111. Hydrometer syringe used to test specific gravity of storage batteries.

cause damage. After the specific gravity reading has been taken, the electrolyte should be returned to the cell from which it was withdrawn.

(2) The condition of the battery can be determined accurately if the density of the electrolyte is known. Most lead-acid storage batteries have an electrolyte composed of sulphuric acid and water whose specific gravity is 1.280 to 1.300 when fully charged. When the battery discharges, the electrolyte becomes less dense because the sulphuric acid in the electrolyte combines with the active material on the plates. The specific gravity of the electrolyte falls to about 1.220 when the battery is half discharged, and to 1.150 or less when the battery is fully discharged. Charging the battery causes the density of its electrolyte to increase gradually and when it is fully charged, the specific gravity of the electrolyte is at its highest value.

(3) Because the density of a liquid changes with changes in temperature, corrections must sometimes be applied to the specific gravity readings obtained with a hydrometer. Therefore, specific gravity values for battery electrolytes usually are given for a standard temperature of 80° F.

84. Megger

a. GENERAL DESCRIPTION AND USE. The megger is a portable insulation-resistance test set for measuring large values of electrical resistance. It consists of a high-range ohmmeter and a hand-operated d-c generator, mounted in the same case. The resistance range of the megger usually extends from 0 to 1,000 megohms or more, and the ohmmeter is of special design. The generator may deliver a potential of 500, 1,000, or 2,000 volts at the test terminals, but in military applications a 500-volt d-c generator generally is used. A megger is shown in figure 112 with its carrying case and test leads. The face of the indicating meter is at the top of the test set, and the hand crank for the d-c generator is at the right.

b. FUNCTIONING OF PARTS.

(1) When the crank of the megger (fig. 113) is operated, the d-c generator produces a 500-volt d-c potential with the polarity indicated. Electron current flows from the negative terminal of the generator, through the potential coil, which forms part of the ohmmeter movement, through the large resistor, R_2, and back to the positive terminal of the generator. The magnetic field set up by the potential coil reacts with the field set up by the permanent magnet in such a way that the coil and pointer assembly move in a counterclockwise direction. With nothing connected to the test set, the only current flowing is the current just described, and the pointer indicates infinite resistance on the scale.

(2) Placing an unknown resistance between the LINE and GROUND terminals provides another path for current flow. This path is from the negative terminal of the generator, through the current coil (part of the ohmmeter movement), resistor R_1, the LINE terminal, the unknown resistance, and the GROUND terminal, to the positive side of the generator. The magnetic field set up by the current coil tends to move the coil and pointer assembly in a clockwise direction. If the unknown resistance is extremely low, most of the current flows through the current coil and the pointer moves close to 0 on the scale. If the value of the unknown resistance is increased, less current flows through the current coil with respect to the fixed amount of current in the potential coil and the pointer moves from 0 toward infinity on the scale.

(3) This meter is called a true, or differential, ohmmeter, because the position of the pointer is determined by the difference between two forces. One force tends to move the pointer toward 0 and the other force tends to move it toward infinity. The system comes to rest at a point where the two forces

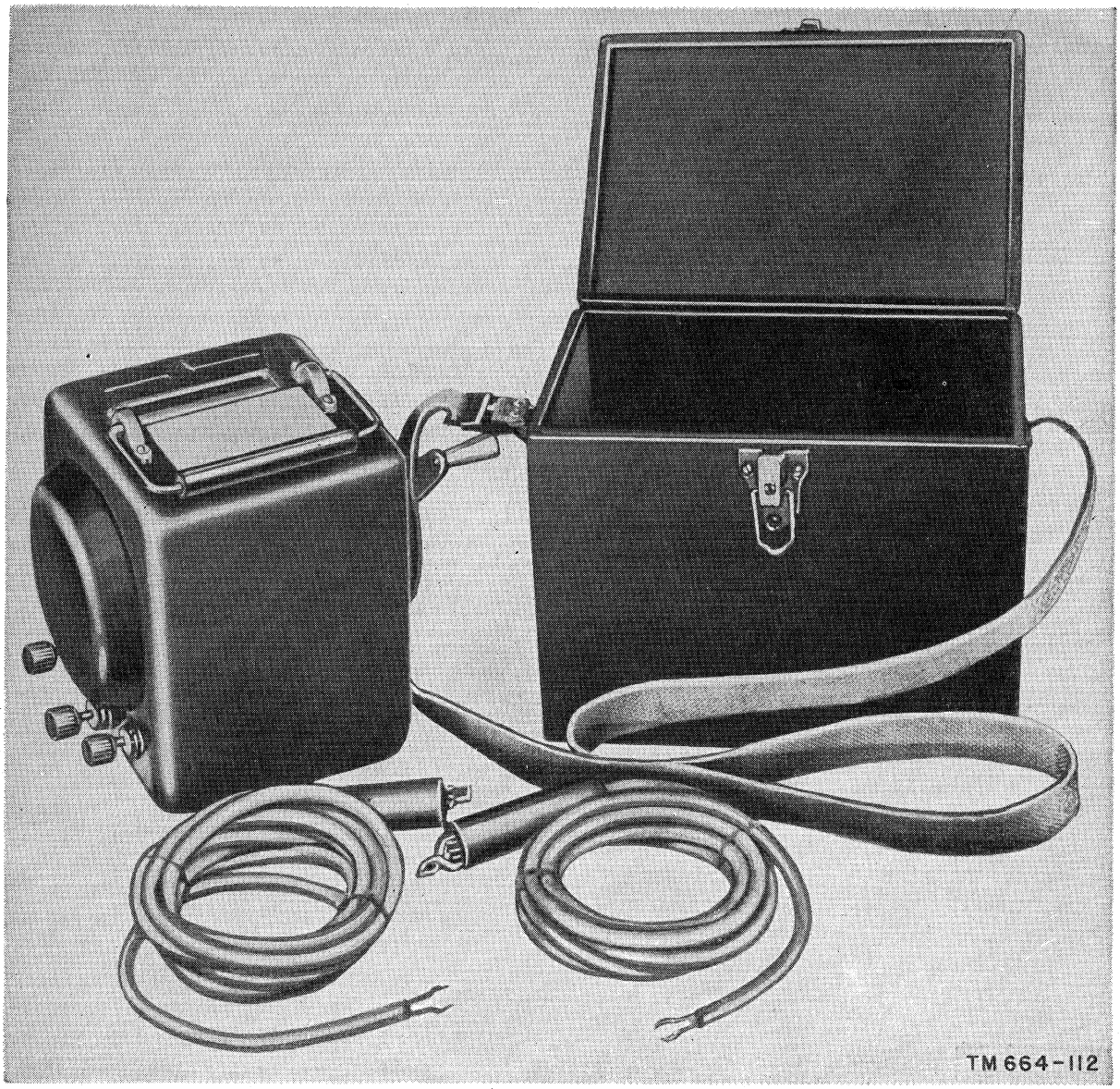

Figure 112. Megger, a portable insulation-resistance test set with carrying case and test leads.

are balanced, the position depending on the value of the unknown resistance. This position does not depend on the voltage generated within the equipment as in an ordinary ohmmeter.

(4) A guard circuit is used for measurements over 100 megohms. The guard circuit, shown in light lines in the figure, consists of a metal ring which surrounds the LINE terminal, metal plates on which resistors R_1 and R_2 are mounted, and a metal shield cable which connects the ring and plates to the GUARD terminal. This circuit prevents leakage currents along the surface of the insulating instrument case between the LINE terminal and GROUND which can affect the reading. These surface leakage currents can flow between the guard circuit and the GROUND terminal without going through the meter movement.

(5) The d-c generator is operated by a

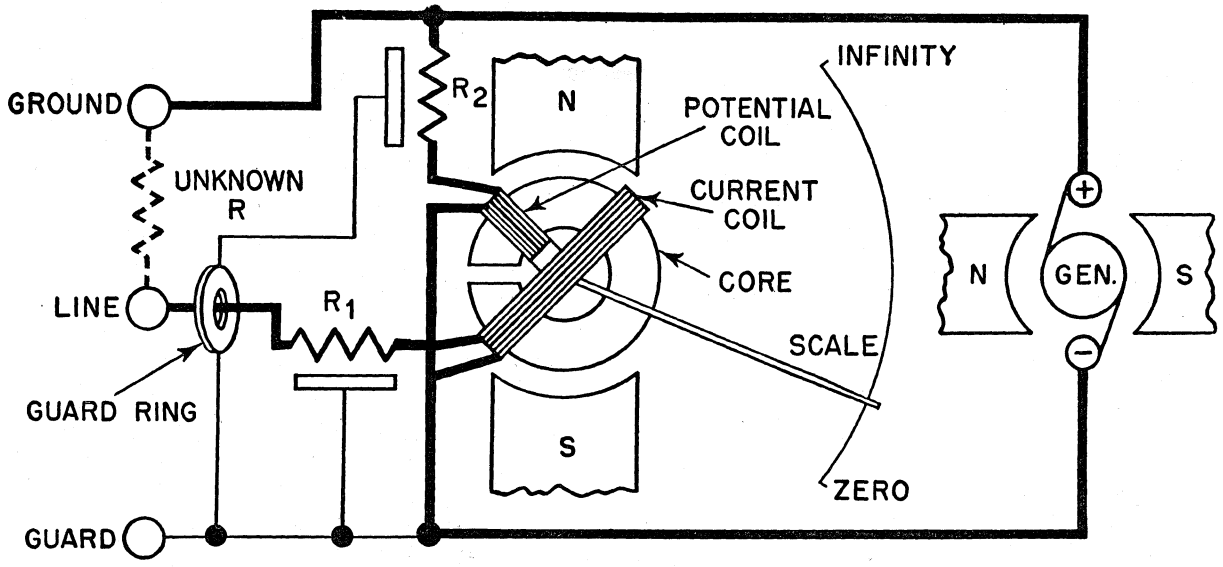

Figure 113. Schematic diagram of megger.

hand crank through a gear train and clutch assembly. The clutch mechanism slips when a certain speed of hand-crank rotation is reached, keeping the generator at a constant operating speed. Therefore, the output voltage will be fairly constant as long as the crank is rotated above the speed at which the clutch slips.

c. OPERATION.

(1) Before connecting the megger to the equipment to be tested, all power should be disconnected. Because of the small amount of torque and the lack of balance springs in the movement, the megger should be kept in an upright position and placed away from strong external magnetic fields so that the reading is not affected. The test leads then are connected to the megger and the megger tested for leakage. With the test lead open, the meter should read infinity; when the test leads are short-circuited, the meter should read zero.

(2) Finally, the test leads are connected to the device whose insulation resistance is to be checked. The hand crank then is rotated until the clutch slips and the meter reading becomes steady. A reading is taken which is compared with the proper value of insulation resistance. It is important that the insulation resistance be measured at the same temperature every time an insulation test is made because the resistance of insulation drops sharply at high temperatures. For example, the insulation resistance between the stator winding of a certain slow-speed generator and the frame is 100 megohms at 85° F. The insulation resistance of this same equipment falls to only 10 megohms at 140° F.

(3) In the test set-up in figure 114, the installation resistance of the windings of a small electric motor is being tested. The line terminals of the motor have been disconnected. The ground lead of the megger is connected to the frame of the motor and the line lead is connected to each winding terminal in turn.

(4) Some typical insulation-resistance values for various equipments are as follows:

(*a*) Between single conductor and shield in multiple conductor cables, 100 to 1,000 megohms.

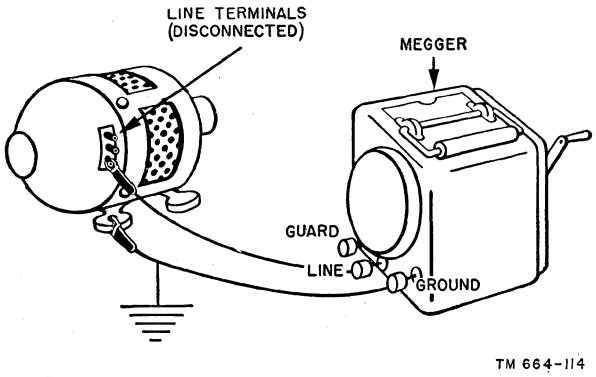

Figure 114. Test set-up for checking insulation resistance of a motor.

(*b*) From one conductor to all other conductors in multiple conductor cables, 100 to 500 megohms.

(*c*) From conductor to conductor or between conductor and ground in complete power circuits, .1 megohm to 2 megohms.

(*d*) From meter circuits to ground, over 20 megohms.

(*e*) Between different meter circuits, over 5 megohms.

(*f*) Between all above-ground circuits and ground in rotating equipment, the minimum insulation resistance should equal the rated voltage of the equipment divided by the kilovolt-ampere or kilowatt rating plus 1,000. This also applies to the resistance from winding to winding or from winding to frame.

85. Battery Tester

a. GENERAL DESCRIPTION AND USE. A battery tester is used to check the terminal voltage and the voltage under load of dry batteries. The equipment consists of a multiple-range voltmeter, a set of battery-loading resistors, a number of multiplier resistors, and a switching arrangement (fig. 115). The battery tester is used to determine the condition of new dry batteries before they are issued for use, or of used batteries to determine whether they are to be replaced.

b. FUNCTIONING OF PARTS.

(1) The battery tester consists of a conventional voltmeter circuit with a number of series-connected multiplier resistors. A large number of battery-loading resistors, ranging from several ohms to some tens of thousands of ohms, are used to provide a load for the battery. The battery-loading resistors are shunted across the battery to be checked at the same time that the voltage reading is obtained (fig. 116). In this way, the terminal voltage of the dry battery can be tested under load. A switch is provided to disconnect the battery-load resistors, and when it is in the open position, the no-load terminal voltage of the battery can be checked.

(2) The battery tester includes a data chart which gives instructions for testing specific dry batteries. The proper multiplier is inserted in series with the voltmeter and the proper load is connected across the terminals where the battery is to be connected. The minimum acceptable voltage reading is given in the instructions for the particular battery and test set-up.

86. Fluxmeter

a. GENERAL DESCRIPTION AND USE.

(1) The fluxmeter is designed to provide qualitative measurements of the flux density of magnets used with ultra-high-frequency and super-high-frequency magnetron oscillators. If the flux density of the magnet used with the magnetron is less than its proper value, the oscillator cannot operate on the proper frequency, and the efficiency of operation is reduced seriously.

(2) The fluxmeter consists of two milliammeters—a probe meter and a gauss meter—in series with a low-voltage battery supply and a rheostat to control the battery current. The probe meter is placed between the poles of the magnet whose flux density is to be

Figure 115. Battery tester being used to check condition of dry battery.

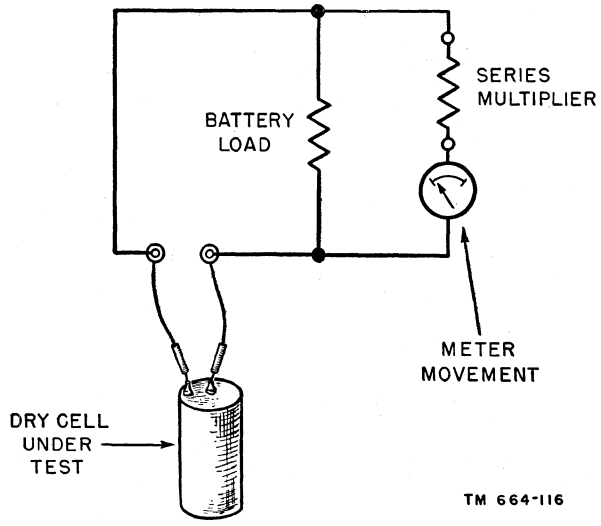

Figure 116. Simplified diagram of battery tester.

measured, and the gauss meter is located in the test equipment itself. When the panel adjustments are made properly, the gauss meter indicates the magnetic flux density in gausses (fig. 117).

(3) A gauss is the unit of measurement of the magnetic lines of force per unit of area, 1 gauss representing one magnetic line of force per square centimeter. Common flux densities of magnetron magnets range from 1,000 to 3,000 gausses for tubes which operate on wavelengths of about 10 cm (centimeters) to 2,500 to 6,000 gausses for tubes which operate on wavelengths of about 3 cm.

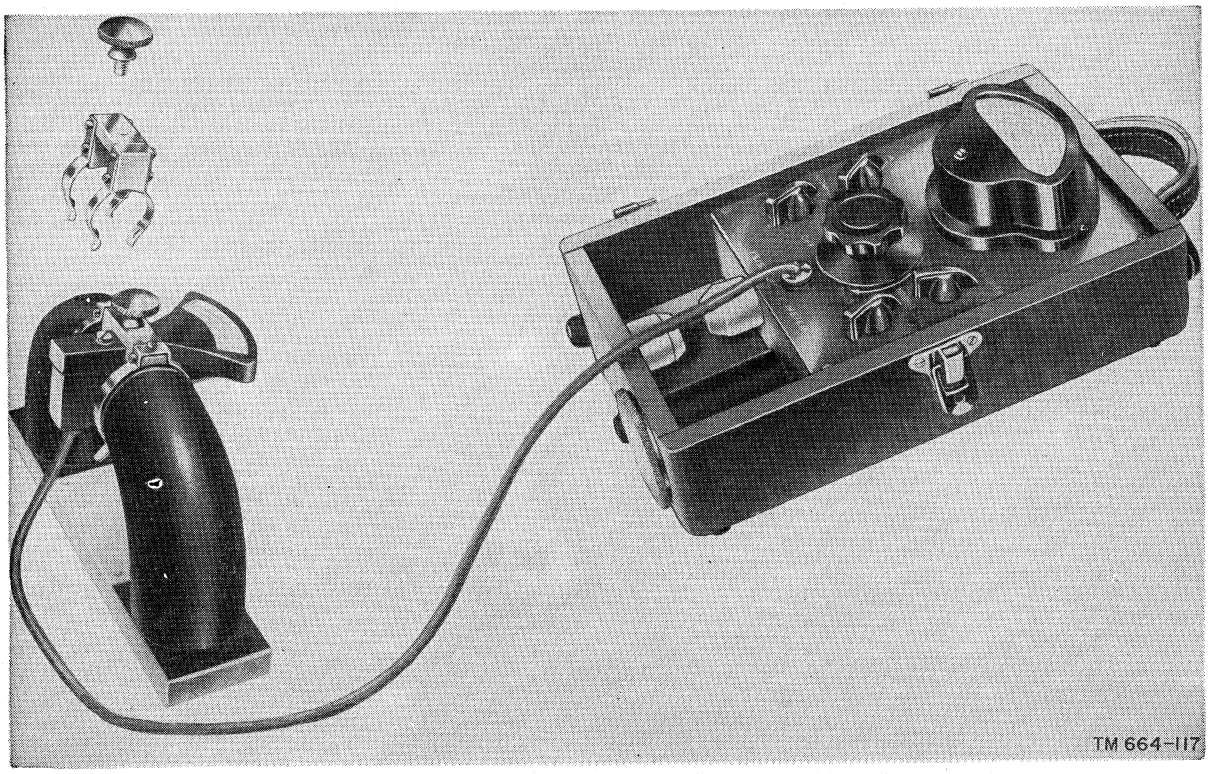

Figure 117. Fluxmeter being used to measure flux density of magnet.

b. FUNCTIONING OF PARTS (fig. 118).

(1) The gauss meter consists of a conventional moving-coil assembly with a suppressed or retarded zero, and the probe meter consists of a meter movement with no permanent field magnet. The magnetic flux needed to operate the probe meter is obtained from the permanent magnet between whose poles it is inserted. The amount of deflection of the probe meter pointer depends on the amount of current through its coil and the flux density in the magnet gap. When the fluxmeter is operated, rheostat R_9 is adjusted for full-scale deflection of the probe meter. If the flux density of the magnet is high, only a small amount of current need flow through the coil. If the flux density of the magnet is low, then a large amount of current must flow through the coil to produce full-scale deflection. The amount of current flowing in the circuit varies inversely with the magnetic flux density being measured.

(2) The gauss meter now can be calibrated in terms of gausses. When the circuit current is low, the flux density is high; when the circuit current is high the flux density is low. Therefore, the smaller the amount of gausses, the greater the meter deflection. Several ranges of measurement are provided by means of S_4 which shunts the probe meter with one of the three resistors, R_4, R_5, or R_6. As larger values of shunt resistance are switched across the probe meter, more current flows through the meter movement. Consequently, a weaker magnetic flux is able to produce full-scale probe-meter deflection. As a result, lower flux densities can be read on the gauss meter. A meter reversing switch, S_2, is used when the magnetic flux causes the pointer to be deflected backward. If this switch were not used, it would be

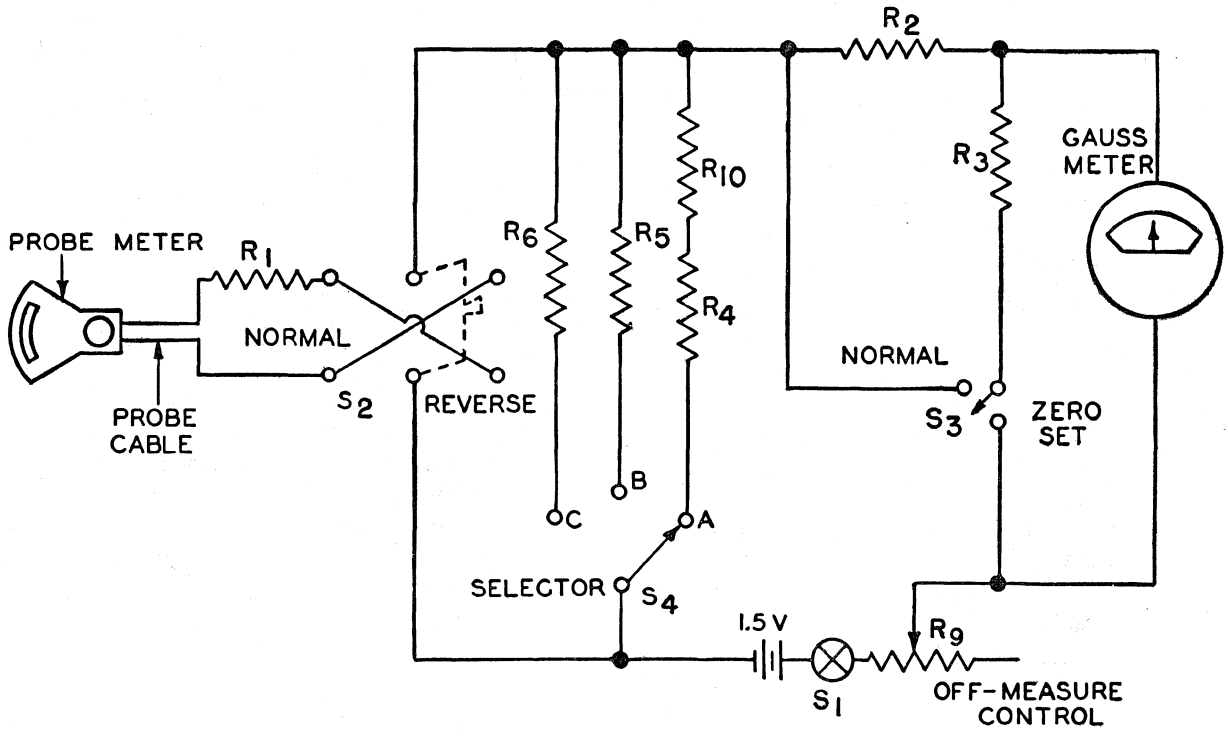

Figure 118. Schematic diagram of fluxmeter.

necessary to reverse the position of the probe meter in the magnetic field.

(3) The ordinary 1-milliampere movement is not used in the gauss meter, since it gives a reading with the probe meter inserted in a very weak magnetic field. As a result, lower values of flux density are read, but the higher readings are bunched close together on a crowded scale. To spread the higher range readings for greater accuracy, the gauss meter has a *retarded zero* which holds the pointer below zero deflection in the undesired lower range. With no current in this meter, the pointer is held off the scale to the left by spring tension. When 1 milliampere of current flows in the circuit, the pointer moves to the first division on the left side of the scale. When 2 milliamperes of current flow, full-scale deflection is produced.

(4) In order for the gauss meter to operate within the proper current range (1 to 2 milliamperes), switch S_3 is used. With this switch in the NORMAL position, resistors R_2 and R_3 are in parallel, and the combination is in series with the gauss meter. This permits maximum current flow in the gauss-meter coil, and rheostat R_9 can be adjusted to produce the 2-milliampere full-scale deflection required. If switch S_3 is placed in the ZERO SET position, R_3 is in parallel with the gauss meter and the current should fall to its lowest scale reading, because it has been reduced to one-half its original value, or 1 milliampere.

(5) Resistor R_1 reduces temperature error caused by shunting the probe meter with different values of resistance. Switch S_1 is used to disconnect the 1.5-volt battery from the circuit when the equipment is not being used.

c. OPERATION.

(1) Before inserting the probe meter between the poles of the magnet to be tested, it is necessary to calibrate the gauss meter. The on-off switch, S_1

(fig. 118), is turned to the ON position and rheostat R_9 is advanced until full-scale deflection of the gauss meter is obtained. S_3 then is switched to the ZERO SET position, and the pointer of the gauss meter should fall to its minimum current reading (maximum flux density).

(2) The probe meter is attached to the proper yoke assembly (fig. 117) and is inserted between the poles of the magnet whose flux density is to be measured. The probe meter should be well seated and centered with the face of the meter in a horizontal position. The gauss meter is magnetically shielded, but powerful magnets too close to it can introduce errors in the reading. Therefore, it is important that the fluxmeter cabinet, containing the gauss meter, be located as far from the magnet as the probe cable allows.

(3) The instrument then is turned on and the rheostat advanced until the probe meter reads full scale. A direct reading in gausses can be made on the gauss meter.

87. Q Meter

a. GENERAL DESCRIPTION AND USE.

(1) The symbol Q is used commonly to designate the ratio of reactance to resistance of a coil (Q is equal to X_L/R) or of a capacitor (Q is equal to X_C/R), or other circuit elements. This factor is of importance in circuit design since it constitutes a *figure of merit* for the reactive element in question. The Q of a series-resonant circuit is important because it determines the amount of voltage step-up or gain obtained. In a parallel-resonant circuit, the impedance of the circuit is directly proportional to the circuit Q. A Q meter is used for making direct measurements of the Q of coils and capacitors, the Q of a circuit, the effective inductance, capacitance, and resistance of a circuit, the resonant frequency of a tuned circuit, or distributed capacitance.

(2) The Q meter consists of a variable-frequency r-f oscillator which introduces a known voltage into a special measuring circuit. The device whose Q is to be measured is made a part of this circuit, and after proper adjustment the value of Q can be read directly from a meter on the instrument panel.

b. FUNCTIONING OF PARTS.

(1) The principle of operation of the Q meter is illustrated in figure 119. An r-f oscillator delivers a voltage to the series circuit composed of L and C. The voltage is measured by noting the value of r-f current, as measured by the thermocouple ammeter, AM, which flows through a known resistance, R. This resistor is small in value (a few hundredths of an ohm) so that it does not affect appreciably the circuit being measured.

(2) The series circuit to which the known voltage is applied is made up of variable capacitor C, located in the Q meter, and coil L. This coil is connected externally to the Q meter between terminals A and B. When the series circuit is made resonant either by adjusting C or changing the oscillator frequency, a low impedance exists between terminal A and ground. The large current in the series-resonant circuit produces large reactive voltage drops across both the coil and the capacitor.

(3) The voltage across variable capacitor C is measured by means of a vacuum-tube voltmeter, which has negligible power consumption. The ratio between the capacitor voltage and the input voltage is equal to the equivalent circuit Q which is X_c/R_e, where R_e is the total equivalent circuit resistance. At resonance, the reactance of the coil being tested and the reactance of the capacitor are equal. Therefore, the ratio between the capacitor voltage and the input voltage is equal to X_L/R_e. This is, by definition, the effec-

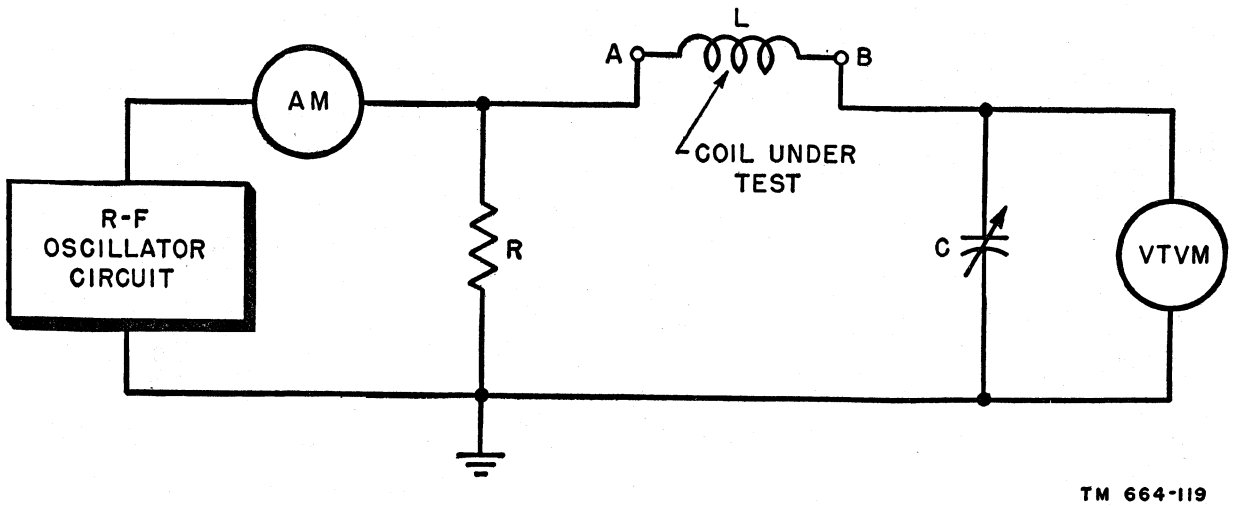

Figure 119. Fundamental circuit of Q meter.

tive Q of the coil or other impedance connected between terminals A and B.

c. OPERATION.

(1) The coil or other circuit whose Q is to be measured is connected to the proper terminals at the top of the Q meter (fig. 120). Power is applied to the equipment and the oscillator frequency is set to the frequency at which the Q is to be measured. This is done by means of the two controls located at the left side of the panel. The lower of these two controls is the oscillator range switch, and the upper control with the large dial is the oscillator tuning control. The frequency range of the oscillator used in the Q meter shown is from 50 kc to 75 mc.

(2) The coil whose Q is to be measured then is resonated by means of the two variable capacitors contained in the Q meter. The tuning capacitors are calibrated directly in micromicrofarads and are operated by two controls located at the upper right corner of the operating panel. The large dial tunes the main tuning capacitor (450 $\mu\mu$f maximum capacitance), and the small dial to the right tunes the vernier capacitor. The vernier capacitor is in parallel with the main tuning capacitor and allows small capacitance adjustments. Resonance is indicated by a maximum reading on the upper meter at the center of the panel. This meter is associated with the vacuum-tube voltmeter circuit which measures the reactive voltage across the capacitor and is calibrated directly in values of Q.

(3) The lower meter at the center of the panel indicates the output current of the self-contained r-f oscillator. This meter is calibrated so that its reading is used as a multiplier for the top voltmeter. For example, assume that the oscillator is adjusted to its maximum output current by means of the coarse and fine oscillator output controls located at the lower right side of the panel. Under these conditions, the r-f current through the thermocouple ammeter is .5 ampere and the calibration on the output current meter is 1. This indicates that the voltmeter readings are multiplied by 1; that is, the readings are direct. When the output of the oscillator is reduced to one-half its original value, the meter *falls* to 2 on the scale. This indicates that the readings of Q on the voltmeter are to be doubled.

88. Neon, Headset, and Lamp Continuity Testers

a. GENERAL DESCRIPTION AND USE.

(1) Neon, headset, and lamp continuity

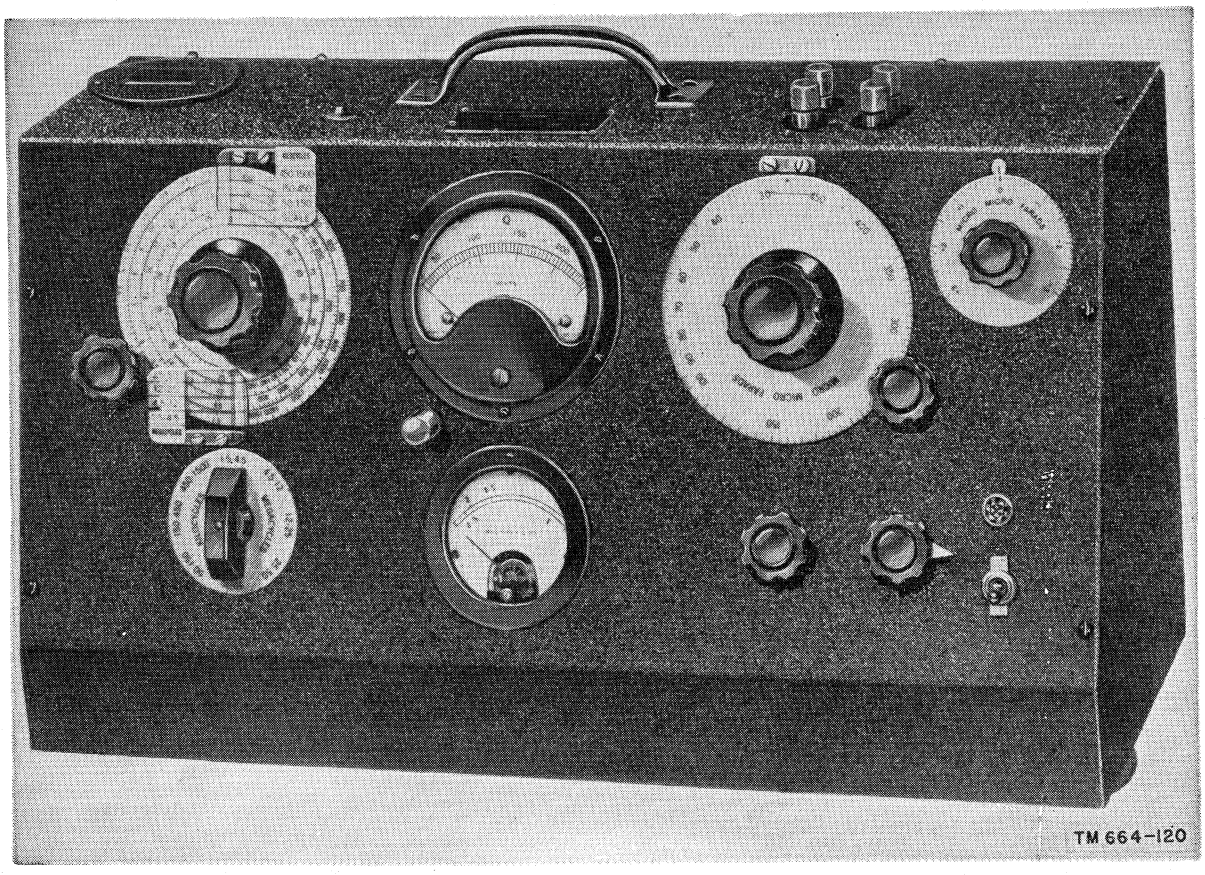

Figure 120. Typical Q meter.

testers are simple pieces of test equipment used to check the continuity of fuses and line circuits. These testers do not give accurate qualitative measurements such as can be obtained with a meter. However, their simplicity is of considerable advantage when open- and closed-circuit tests are made. The neon and lamp testers also can be used to distinguish between a-c and d-c supplies and to test capacitors.

(2) These testers consist of ordinary low-voltage incandescent lamps, neon lamps, or headsets and a pair of leads for connecting the indicator to the circuit to be tested. In some testers a switching arrangement allows a source of voltage to be inserted in series with the test lamp, so that circuits with no voltage applied to them can be checked.

b. FUNCTIONING OF PARTS.

(1) The operation of a neon and lamp continuity tester can be analyzed by means of the schematic diagram shown in figure 121. When the tester is used to check the continuity of circuits, S_1 is placed in the EXT V (external voltage) position and S_2 is closed. The power plug then is connected to a 117-volt, a-c or d-c power source and test leads are applied to the circuit to be tested. If the circuit is continuous, current flows through the incandescent lamp, X_1, the neon lamp, X_2, and the series limiting resistor, R_1, and both lamps light. If the circuit is open, no current flows and neither lamp lights.

(2) When used to test fuses, S_2 is opened and the incandescent lamp is removed from the circuit. The fuse to be checked is removed or disconnected from its

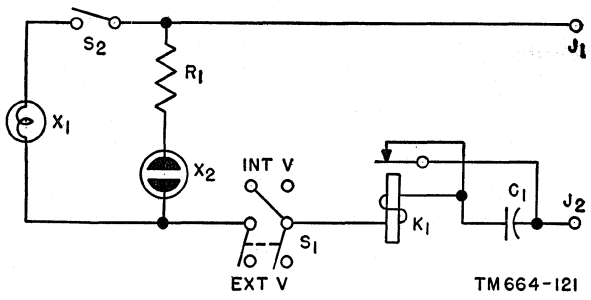

Figure 121. Schematic diagram of neon and lamp continuity tester.

circuit and the test leads are connected across it. When the fuse being tested is good, there is a continuous circuit and the neon lamp lights. The neon lamp draws only a few milliamperes and therefore it is possible to check fuses with a low current-carrying capacity. In checking capacitors, it is necessary to plug the tester into a d-c power source. With S_2 open, the test leads are connected across the capacitor, and a series of small flashes appears in the neon lamp. The amount of time required for the lamp to stop flashing depends on the size of the capacitor and when the capacitor is fully charged, the lamp stops glowing. If the capacitor is completely shorted, the lamp glows continuously, and if it has considerable leakage the lamp flashes continuously.

(3) The tester can be used also to distinguish between a-c and d-c voltages and to check for the presence or absence of voltage in a circuit. When S_1 is switched to the INT V (internal voltage) position and S_2 is opened, the neon lamp with its limiting resistor and relay K_1 with its contacts form a series circuit. The test leads then are connected to the live circuit to be tested and if the voltage is approximately 55 volts ac or 90 volts dc, the neon lamp glows. When both plates of the neon lamp glow, the voltage being tested is ac; when only one plate glows, the voltage is dc; if the lamp does not glow, there is either no voltage or it is too low to ionize the lamp.

(4) Applying a voltage much higher than several hundred volts will cause the neon lamp to be damaged because of excessive current flow. When a high current flows through the circuit and through the relay winding, the relay, *K*, is energized and the contacts open the circuit.

(5) A headset continuity tester consists of a high-impedance headset with test leads. The headset can be tapped across live telephone or telegraph circuits for monitoring or for determining whether the lines are continuous up to the point of connection, but it should not be placed across high-voltage lines. A tone generator sometimes is connected to the line being tested and the headset connection is moved along the line to locate broken or open circuits. As long as the tone is heard in the headset, the line is assumed to be continuous.

c. OPERATION.

(1) The incandescent lamp in figure 122 is seen through the window at the left side of the panel and the neon lamp is seen through the right-hand window. Below the incandescent lamp is a switch to connect or disconnect it from the tester. Below the neon lamp is a switch to connect the test set to a power source through the line cord or to disconnect the line cord completely. The test leads are plugged in the jacks at the bottom center of the panel. A cover with schematic diagrams and parts list is shown above the panel.

(2) To operate, it is necessary only to set up the switches described above, insert the power plug into a suitable power source, and apply the test leads to the circuit to be tested.

89. Signal Tracer (Chanalyst)

a. GENERAL DESCRIPTION AND USE. The chanalyst is used to localize faulty components in radio receivers and amplifiers and to check these devices for intermittent faults. It includes provisions for signal tracing r-f, i-f, and a-f signals; for checking tube and stage gain in r-f, i-f,

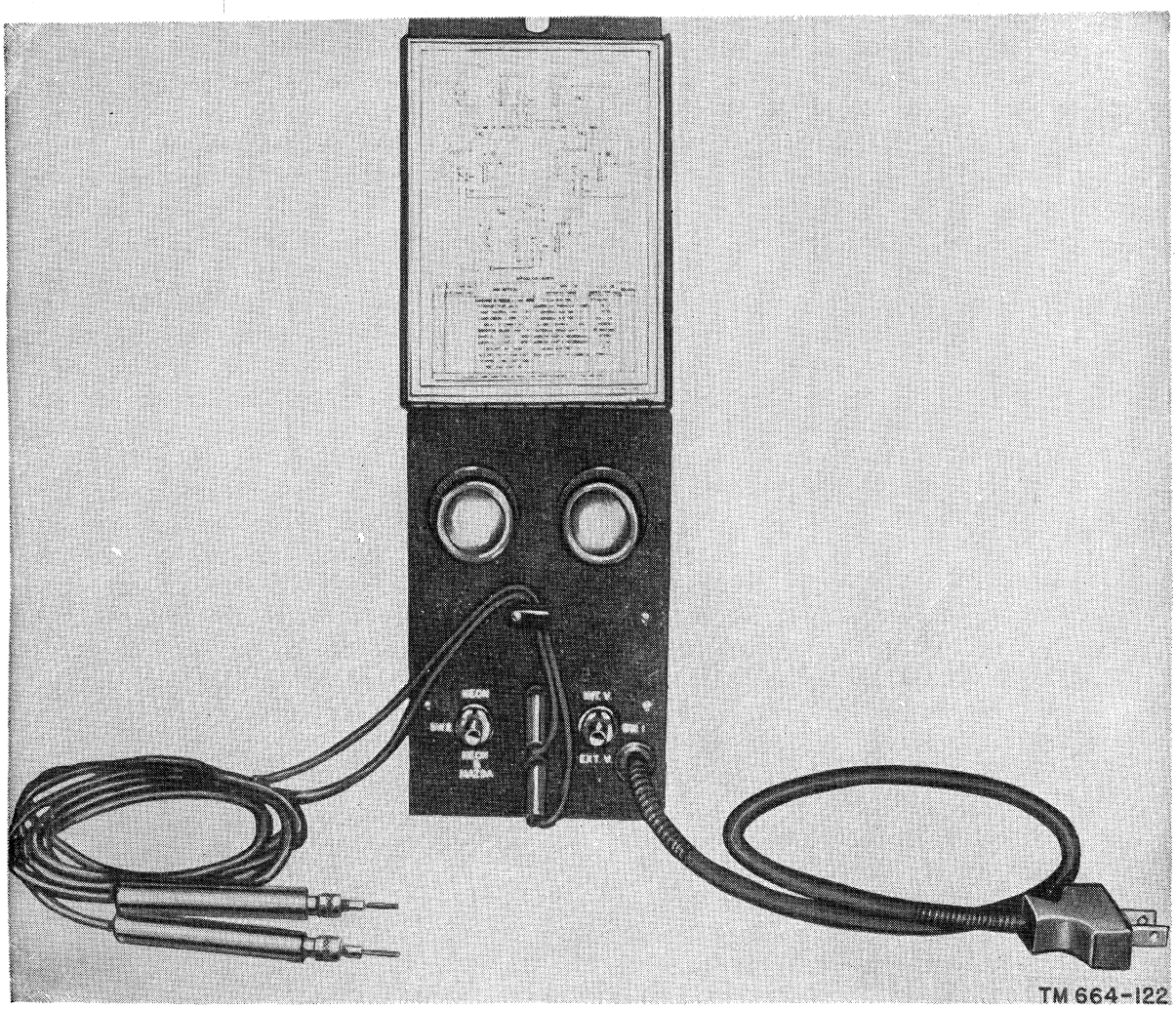

Figure 122. Typical neon and incandescent lamp tester.

and a-f circuits; for measuring d-c voltages under operating conditions; and for testing a-c power consumption. The chanalyst is composed of four separate channels with associated controls and electron-ray indicators (tuning eyes) are used as output indicators. The four channels are the r-f, i-f channel, the oscillator channel, the a-f channel, and the wattage indicator channel. An electronic voltmeter also is incorporated in the test set so that the output voltage of the various channels can be measured directly, or other d-c voltage measurements can be made.

b. FUNCTIONING OF PARTS.

(1) The r-f i-f channel consists of three stages of tuned amplification, V_1, V_2, V_3, a diode rectifier (part of V_4), an electron-ray indicating tube, V_5, and an r-f i-f pick-up cable (fig. 123). The amplifiers are turnable in three bands, from 96 to 1,700 kc. An input signal from the r-f or i-f sections of a receiver being tested is coupled through the pick-up cable to the three stages of amplification. The output of the third amplifier is rectified by the r-f i-f diode applied to the electron-ray tube which is used as the output indicating device.

(2) The greater the amplitude of voltage applied to the electron-ray tube, the smaller is the shadow angle. Level and multiplier controls in the channel provide calibrated attenuation to signals under test. Therefore, if the shadow

angle of the tuning indicator is maintained constant, the settings of these controls provide a means of measuring the relative levels or two or more test signals. The output of the r-f i-f diode is also applied to a headset jack, J_5, and a meter jack, J_7. A headset can be connected to the headset jack so that phone monitoring of modulated test signals is possible, or the electronic voltmeter in the chanalyst can be connected to the meter jack for accurate measurements.

(3) The oscillator channel consists of a single r-f amplifier, V_6, a diode rectifier (part of V_8), an electron-ray indicating tube, V_7, and an oscillator pick-up cable. A signal is applied from the oscillator section of the receiver being tested, through the pick-up cable to the r-f amplifier. The r-f amplifier is tunable in three ranges, from 600 to 15,000 kc, and its output is rectified by the oscillator diode and applied to the oscillator electron-ray indicator. The greater the amplitude of signal applied to the indicator tube, the narrower is the shadow angle. A level control is provided in this channel to provide variable attenuation to signals under test. This allows the shadow angle of the indicator tube to be set at a certain reference value. When a second test signal is applied and the level control is readjusted for the same shadow angle, a means of measuring the relative levels exists. The output of the oscillator diode is applied to meter jack J_8. This allows the built-in electronic voltmeter to be connected to this channel for accurate measurement.

(4) The a-f channel consists of a single stage of audio amplification (part of V_8), an a-f diode rectifier (part of V_8), an electron-ray tube, V_9, and an a-f pick-up cable. A signal is applied from the audio section of the receiver or audio amplifier being tested through the pick-up cable to the a-f amplifier. The output of this amplifier is applied through a diode rectifier to an electron-ray indicator tube. Level and multiplier controls are used in conjunction with the indicator tube for obtaining relative signal strengths. A headset can be connected to jack J_6 to permit monitoring of the signal.

(5) The wattage indicator channel consists of a rectifier diode (part of V_4), a wattage indicator electron-ray tube, V_{11}, and an input receptacle. The equipment whose a-c power consumption is to be measured is plugged into the input receptacle. The voltage applied to the rectifier diode is determined by the current flowing in the primary circuit of the equipment being tested and the output of the rectifier is applied to the electron-ray tuning indicator. A level control is used which is calibrated directly in watts (from 30 to 250 watts). When this control is advanced until there is a zero-degree shadow angle, the power can be read direct.

(6) The electronic voltmeter circuit comprises a d-c amplifier, V_{10}, a meter, M_1, and a test lead. An internal power supply, rectifier V_{12}, delivers operating voltage to all other circuits. The power switch is provided with a STAND-BY position in which the four electron-ray indicator tubes are deenergized. This prolongs the life of the fluorescent material used in these tubes.

c. OPERATION.

(1) The chanalyst (fig. 124) is connected to a 117-volt a-c line and the power switch is turned on. The receiver to be serviced is energized also, and a ground connection is made from the test set to the low side of the receiver. To trace the signal through the r-f and i-f sections of the receiver the proper pick-up cable is inserted in the RF-IF input jack. The LEVEL and MULTIPLIER controls located on the left side of the panel are set to the 1 positions, and the frequency of the chanalyst is adjusted to the frequency of the equipment being checked.

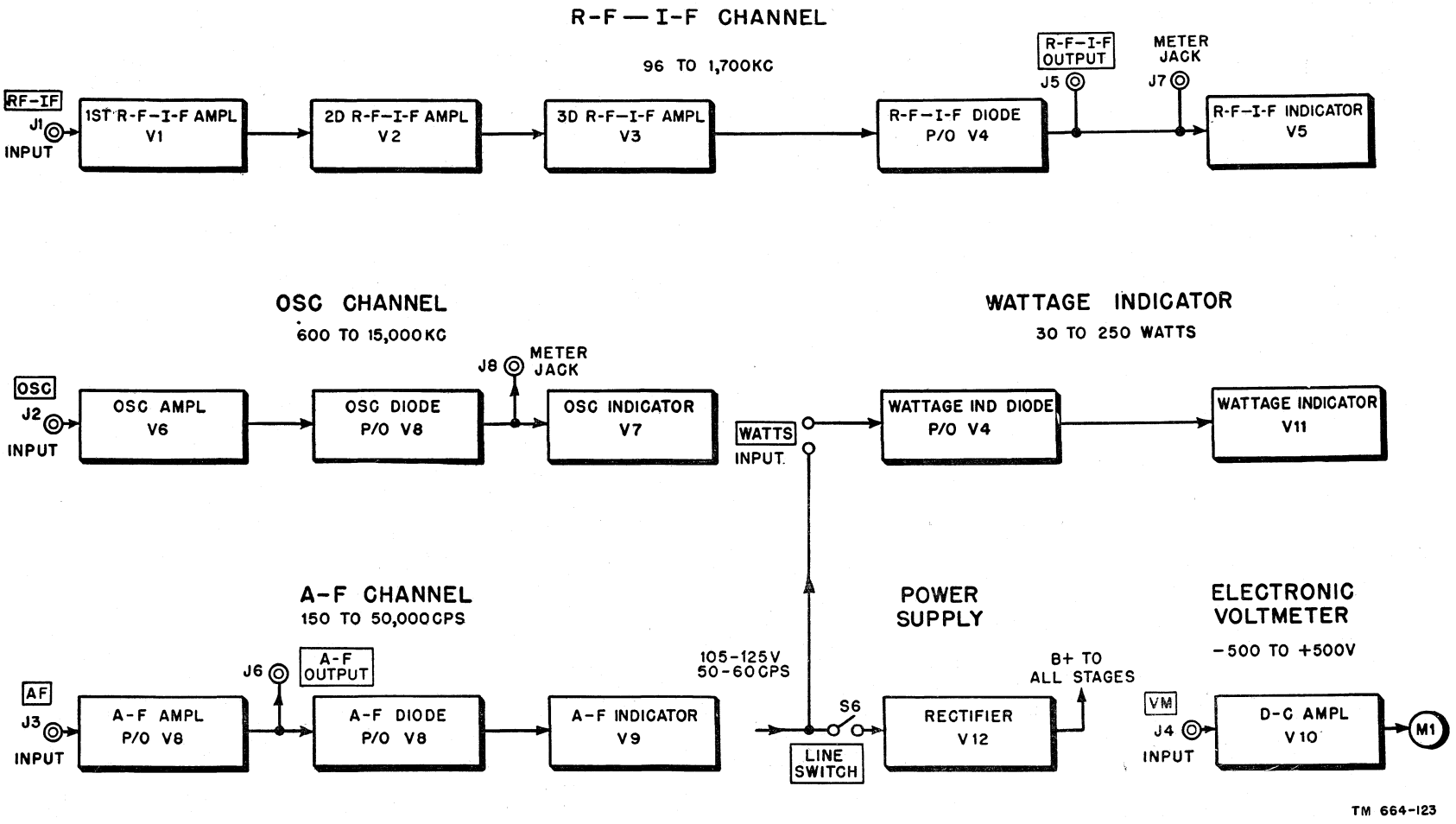

Figure 123. Block diagram of chanalyst signal tracer.

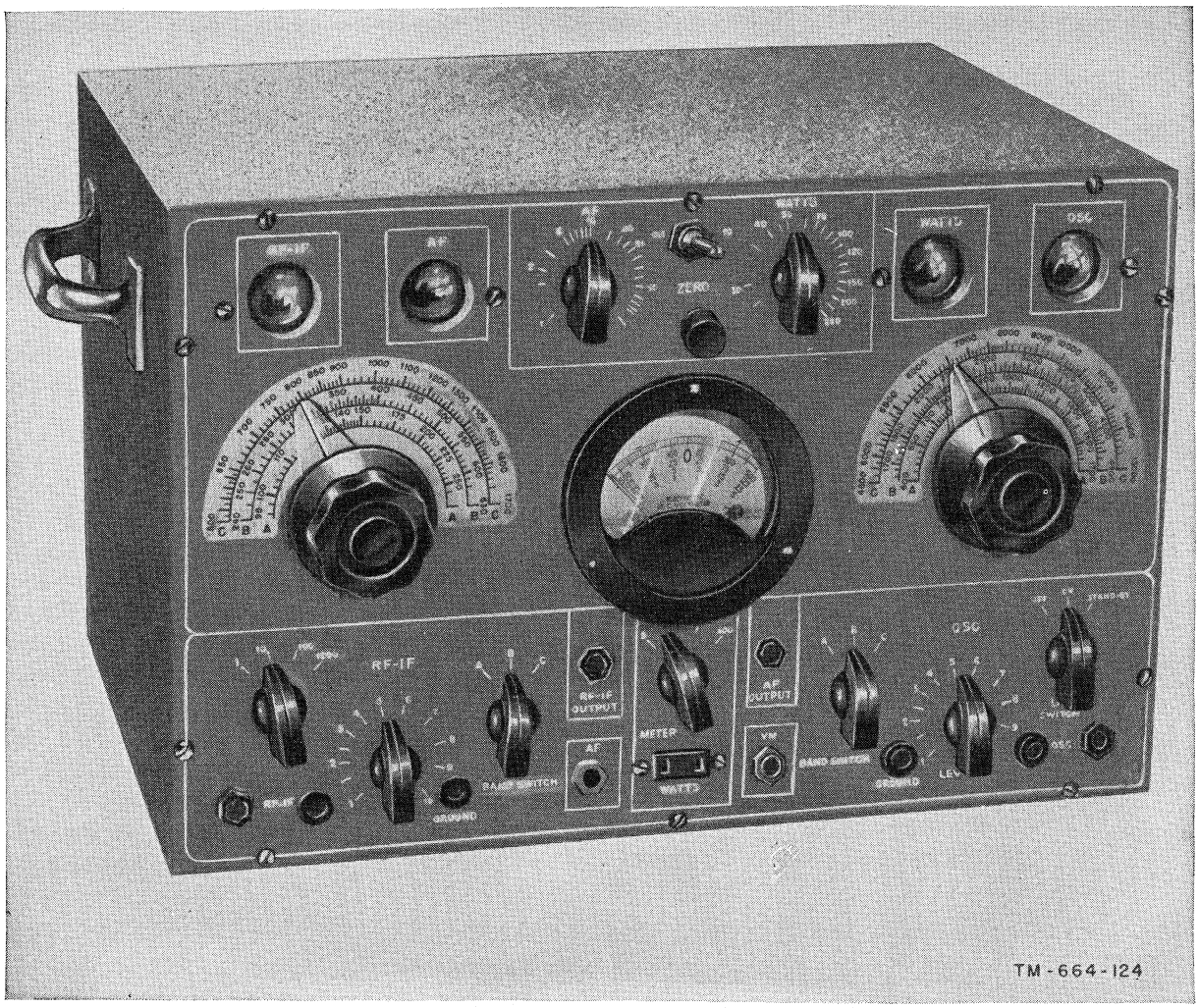

Figure 124. Chanalyst signal tracer.

(2) The presence of a signal at the pick-up probe is indicated by a decrease in the shadow angle of the indicator tube. The controls on the test set should be adjusted to give zero shadow angle, and this point is used as a reference level for further adjustments, since it is a condition readily duplicated. The signal then can be traced by moving the pick-up cable probe to another point in the receiver being checked. For example, the probe is placed, in turn, on the antenna terminal, on the grid terminal of the r-f amplifier, on the plate terminal of the r-f amplifier, on the grid terminal of the i-f amplifier, on the plate terminal of the i-f amplifier, and so on. As the signal being traced increases in amplitude, the sensitivity of the chanalyst is reduced by advancing the MULTIPLIER and LEVEL controls to obtain zero shadow angle on the indicator tube. This makes it possible to measure changes in relative signal strengths by noting the settings of these controls. If the signal disappears or is reduced in amplitude during the tracing procedure, a fault is indicated.

(3) The same procedure is used to check the oscillator section of a receiver. The connections and controls, however, are located on the right side of the chanalyst panel. An audio signal can be traced by using the proper pick-up

cable in the AF input jack, and operating the controls at the top left center of the test set. The indicator tube for the audio channel is located to the right of the r-f i-f indicator tube.

(4) To check the power consumed, the equipment is plugged in the WATTS receptacle on the panel. The WATTS level control at the top right center is adjusted until the WATTS indicator tube shadow just closes. The amount of power consumed by the circuit then is read directly from the WATTS level control. To use the electronic voltmeter, the proper pick-up cable is inserted in the VM input jack, the meter pointer is centered by means of the ZERO control, the proper range is set, and the probe is applied to the circuit whose voltage is to be measured. The meter controls are located at the center of the panel adjacent to the meter.

90. Crystal Test Sets

a. GENERAL DESCRIPTION AND USE.

(1) A crystal test set is a precision oscillator used to test the activity of quartz crystals, at room temperature and over a designated temperature range. The test set also can be used with auxiliary equipment to check the frequency of the crystals.

(2) A crystal test set and some of the auxiliary equipment that must be used with it is shown in figure 125. This includes a low-range meter to indicate the activity of the crystal being tested, a wooden test block and a temperature-controlled oven (in front of the test set).

b. FUNCTIONING OF PARTS.

(1) The test set is designed to simulate the circuits of the equipment in which the crystal actually is used. The circuit in figure 126 is a conventional oscillator in which the crystal to be tested is connected to the crystal terminals between grid and ground of the triode tube. The required inductive plate load is provided by the radio-frequency choke RFC. Feedback occurs through the plate-to-grid capacitance of the tube and through variable capacitor C_2

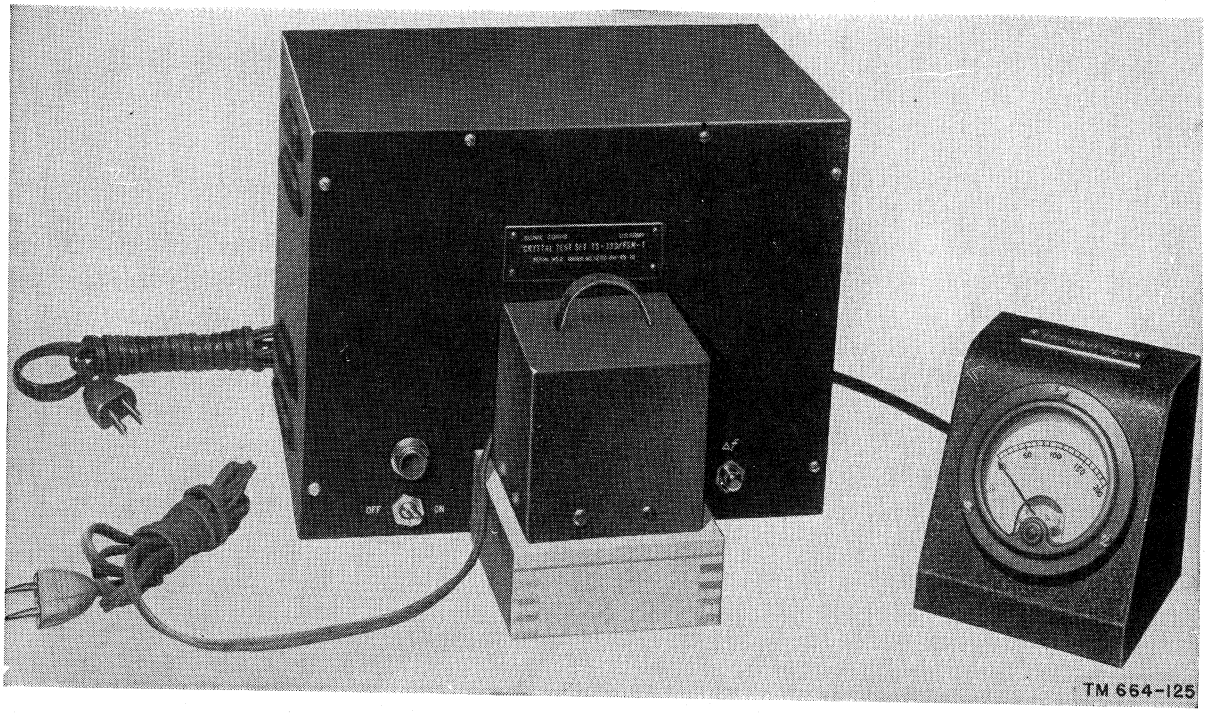

Figure 125. Typical crystal test set.

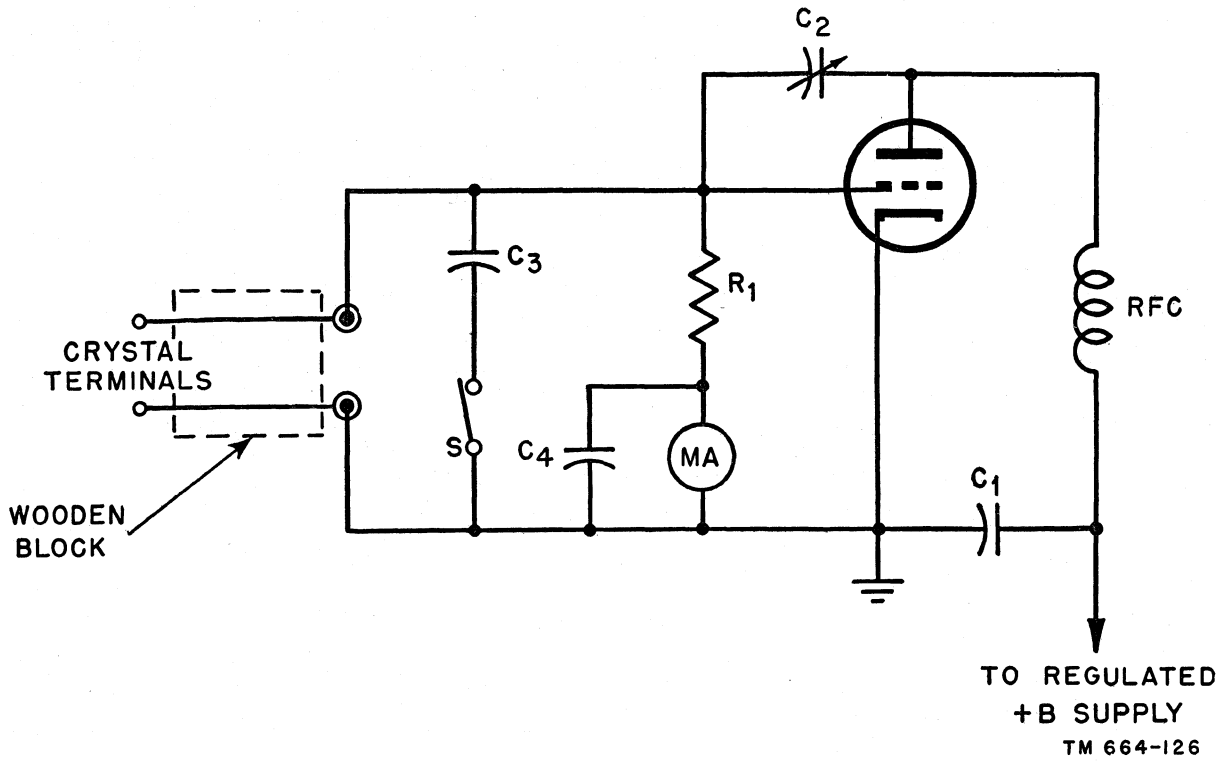

Figure 126. Schematic diagram of simple crystal test set.

which permits the amount of feedback to be adjusted. The crystal to be tested is shunted by the small capacitor, C_3, when the switch is closed. This allows the frequency of the oscillator to be lowered slightly, and is necessary when an auxiliary frequency-measuring assembly is used. Rectified grid current flowing through resistor R_1 provides grid-leak bias for the oscillator and also flows through a low-range current meter, M, which is bypassed by capacitor C_4. The magnitude of the rectified grid current is an indication of the crystal activity. If the crystal does not oscillate, no grid current flows and the meter reading is zero. The more active the crystal, the greater the grid current flow and the higher the meter reading.

(2) Capacitor C_1 is an r-f bypass capacitor from B+ to ground to provide a low-reactance path across the power supply. Capacitor C_3 is used to identify the proper operating frequency when the test set is used in conjunction with frequency-measuring equipment. During this process, the signal produced by the crystal test set is beat with a signal from a standard oscillator, and an audible beat note is heard in a receiver. To determine whether the crystal in the oscillator is operating at a lower or higher frequency than the standard, the switch is closed, and the crystal oscillator frequency is reduced slightly. If the frequency of the oscillator was originally higher than the standard, the beat note now is lower in frequency. If the frequency of the oscillator was originally lower than the standard, the beat note now is higher in frequency.

(3) The frequency produced by a particular crystal test set should be the same as that produced in the actual circuit for which the crystal is intended. If there is a difference in frequency, capacitor C_2 is adjusted to minimize this difference. Provisions are made

in some crystal test sets to correlate the crystal activity. This is necessary so that the crystal activity indicated by the test set is duplicated exactly in the actual circuit for which the crystal is intended. A regulated power supply, not shown, is built in the test set.

c. OPERATION. The crystal to be checked is plugged into a receptacle on the wooden test block shown in figure 125. The test block then is plugged in the front panel of the crystal test set. If activity and frequency measurements are to be made at other than ambient temperature, the crystal oven should be mounted on the test block and energized. A milliammeter is plugged into the test set and power is applied. The activity of the crystal being tested is determined by observing the meter reading and comparing it with the minimum acceptable value. Auxiliary frequency-measuring equipment can now be used to measure the operating frequency of the set.

91. Field-Strength Meters

a. GENERAL DESCRIPTION AND USE.

(1) Field-strength meters are used to measure the relative or absolute value of field intensity produced by an excited transmitter antenna. The meter measures and compares the efficiency of antennas, measures their directivity characteristics, and checks their signal coverage. A field-strength meter is useful is selecting transmitter antenna sites, making surveys of field intensities, and in checking spurious harmonic radiation. Field-strength meters are useful also in tuning and adjusting antennas and antenna systems for maximum radiation.

(2) The purpose of the various transmitter tuning adjustments is to produce the desired amount of radiation at the correct frequency. The field-strength meter actually measures some of the radiated field and provides a true indication of the amount of energy being radiated.

(3) Very sensitive field-strength meters, used by broadcast stations for field-strength survey purposes, are fairly complex devices. These include sensitive receivers, special pick-up antennas whose exact characteristics are known or can be calculated, and some type of calibrating generator. This generator supplies a known amount of signal to the receiver and permits the equipment to be calibrated accurately.

(4) A less sensitive field-strength meter provides only a relative indication of field strength and is often improvised. One of these meters consists of a pick-up antenna, a tuned circuit, a crystal rectifier, and a microammeter. A somewhat wider range field-strength meter uses a d-c amplifier between the rectifier and the meter.

b. FUNCTIONING OF PARTS.

(1) A schematic diagram of a simple relative field-strength meter is shown in figure 127. A short rod type of pick-up antenna is used to deliver a voltage to the tuned circuit. Three inductors are provided with a variable capacitor so that a wide frequency range can be covered. The r-f signal is rectified by a crystal and direct current flows through the microammeter. Two radio-frequency chokes and a bypass capacitor keep r-f out of the meter and prevent it from overloading the tuned circuit. A meter shunt resistor, R_{sh}, can be switched across the meter so that large amounts of current can be measured. The meter reading indicates the relative strength of the field acting on the pick-up antenna and is not directly proportional to the field intensity because of the nonlinearity of the crystal.

(2) A battery-operated meter for reading absolute field strengths directly in terms of microvolts per meter is shown in figure 128. This meter compares the voltage induced in the loop pick-up antenna with the voltage generated by a self-contained calibrated oscillator. The voltage from the loop is applied to a sensitive superheterodyne receiver which incorporates two calibrated attenuators. One attenuator is between

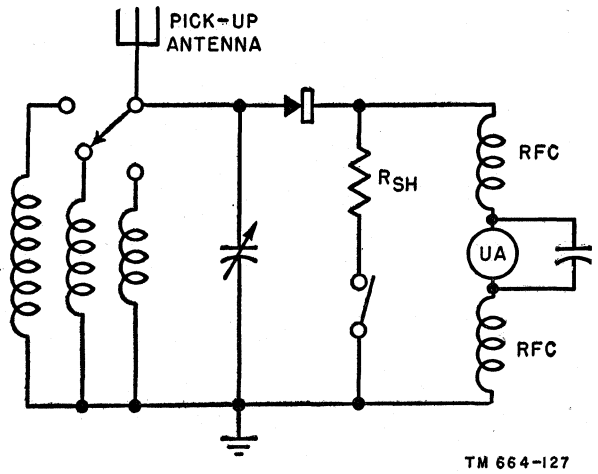

Figure 127. Schematic diagram of simple relative field-strength meter.

the loop and mixer stage and the other is in the first i-f amplifier. The indicating meter in the instrument reads the diode current in the second detector.

c. OPERATION.

(1) The field-strength meter should be on level ground well away from trees, buildings, and power lines. If a rod antenna is used, the rod should be parallel to the direction of the electric field produced by the transmitter antenna. It is advisable to carry the field-strength meter in a circle about the spot where a measurement is to be taken to check for uniformity of the field. If considerable variation in field strength occurs, standing waves are present and a reading is of questionable value.

(2) When the relative field-strength meter is used, it is necessary only to tune the resonant circuit for maximum reading on the meter. When the absolute type is used, the calibrated oscillator must be preset. The attenuators then are adjusted until the second detector current read on the meter is a predetermined value. The field strength can be read directly from the attenuator settings.

92. Summary

a. A hydrometer is used to measure the specific gravity of the electrolyte in a lead-acid storage battery.

b. The principle of operation of a hydrometer is that a floating object is buoyed up by a force equal to the weight of the liquid displaced.

c. The megger is a portable insulation-resistance test set for measuring extremely large values of electrical resistance.

d. The megger consists of a special ohmmeter with a crank-operated d-c generator.

e. A battery tester is used to check the terminal voltage under load and no-load conditions of dry batteries.

f. A conventional voltmeter is used in the battery tester along with various battery-loading and series-multiplier resistors.

g. A fluxmeter measures magnetic flux density of permanent magnets used with magnetron oscillator tubes.

h. The basic fluxmeter circuit consists of two series-connected milliammeters, a source of voltage, and a rheostat. One of these meters uses the magnetic flux produced by the magnet being tested.

i. A Q meter is used to measure directly the Q of coils, capacitors, and circuits.

j. The operation of the Q meter is based on the voltage step-up obtained in a series-resonant circuit.

k. Neon lamp, headset, and incandescent lamp continuity testers are simple devices used to check the continuity of fuses and line circuits.

l. The chanalyst is used for dynamic testing of radio receivers and amplifiers by means of a signal tracing technique.

m. Separate channels are provided in the chanalyst for r-f and i-f measurements, oscillator measurements, a-f measurements, and power-consumption measurements. A built-in electronic voltmeter is provided also.

n. Crystal test sets are precision oscillators used to test the activity of quartz crystals. Fre-

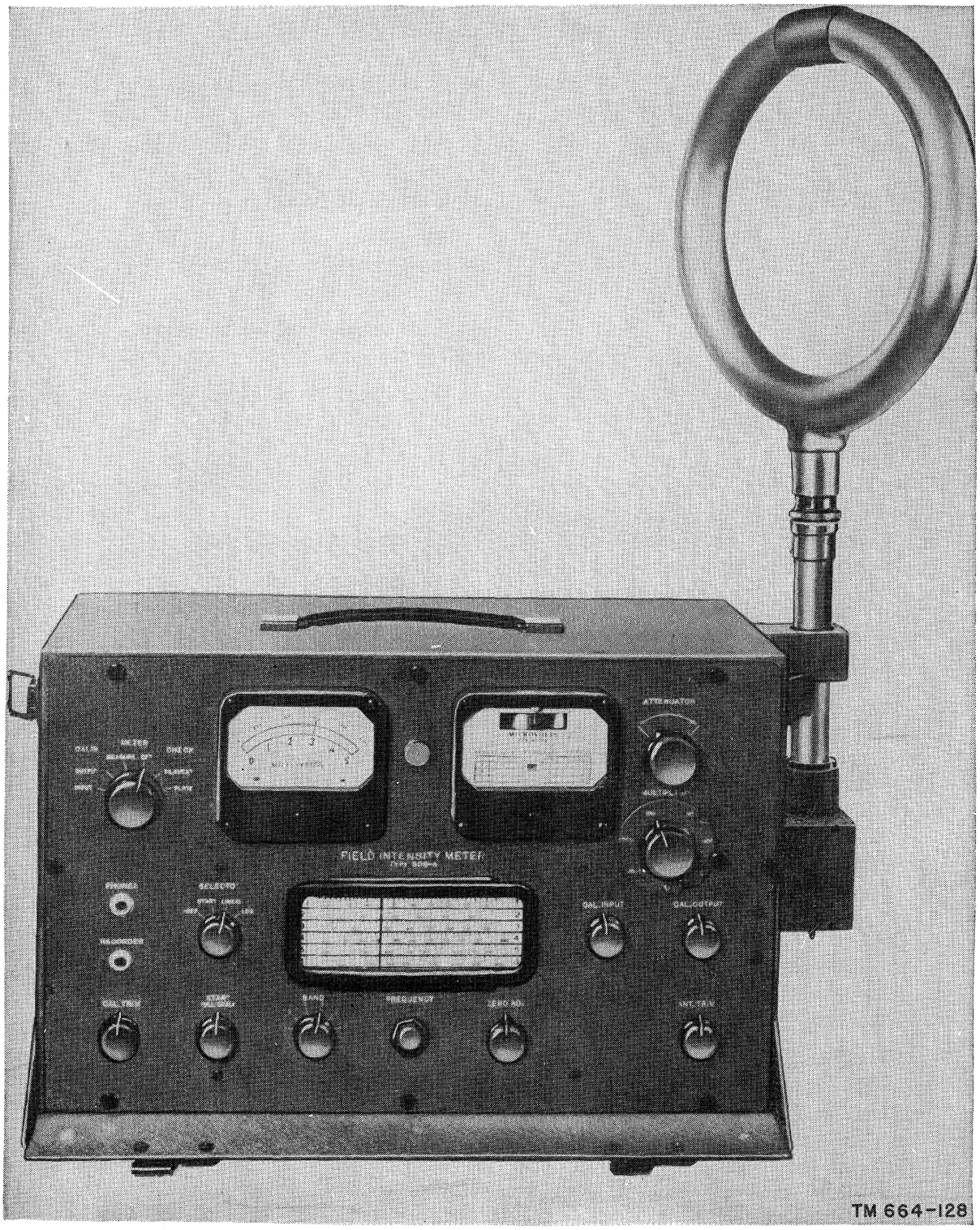

Figure 128. Typical absolute field-strength meter.

quency measurement also is possible when auxiliary equipment is used.

o. Field-strength meters are used to measure the relative or absolute value of field intensity produced by an excited transmitter antenna.

93. Review Questions

a. For what purpose is the hydrometer used?

b. What is meant by specific gravity?

c. How does the ohmmeter used in the megger differ from an ordinary ohmmeter?

d. Give two specific uses of the megger.

e. What is the purpose of a battery tester?

f. Explain the principle of operation of the fluxmeter.

g. What type of meter movement is used in the gauss meter?

h. Give two specific uses for the Q meter.

i. How is the Q meter used to measure inductance?

j. What is one advantage of the neon lamp continuity tester over the meter type?

k. Give a disadvantage of the neon and lamp continuity tester.

l. What is the principle of operation of the chanalyst?

m. Why is it necessary to correlate a crystal test set?

n. How is crystal activity checked with a crystal test set?

o. Give two uses of field-strength meters.

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